

Proceedings of the
Global Conference on Aquaculture 2010

Farming the Waters for People and Food

Editors

Rohana P. Subasinghe

J. Richard Arthur

Devin M. Bartley

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Aquaculture activities. Courtesy of Francesco Cardia and Melba Reantaso.



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**Food and Agriculture Organization of the United Nations
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**Network of Aquaculture Centres in Asia-Pacific
Bangkok, Thailand 2012**





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Foreword

The Food and Agriculture Organization of the United Nations (FAO) and the Network of Aquaculture Centres in Asia-Pacific (NACA) are pleased to present *Farming the Waters for People and Food*, the Proceedings of the Global Conference on Aquaculture 2010.

The Global Conference on Aquaculture 2010, organized jointly by FAO, the Network of Aquaculture Centres in Asia-Pacific (NACA) and the Royal Thai Department of Fisheries (DoF), was held from 22 to 25 September 2010. It sought to bring together a wide-ranging group of experts and important stakeholders to review aquaculture progress and the further potential of this sector, as a basis for improving the positioning of the sector and its mandate within the global community.

The objectives of the Conference were to: (a) review the present status and trends in aquaculture development; (b) evaluate the progress made in the implementation of the 2000 Bangkok Declaration and Strategy; (c) address emerging issues relevant to aquaculture development; (d) assess opportunities and challenges for future aquaculture development; and (e) build consensus on advancing aquaculture as a global, sustainable and competitive food production sector.

In order to achieve these objectives, the Global Conference was conducted in four separate sessions over a period of four days. The Conference's technical programme included: (1) two keynote addresses; (2) three invited guest lectures; (3) six regional aquaculture development trends reviews and one global synthesis; and (4) 41 thematic presentations covering six broad thematic areas which included: (i) resources and technologies for future aquaculture; (ii) sector management and governance; (iii) aquaculture and the environment; (iv) responding to market demands and challenges; (v) improving knowledge, information, research, extension and communication in aquaculture; and (vi) enhancing aquaculture's contribution to food security, poverty alleviation and rural development.

The Global Conference triggered great interest among a wide range of stakeholders (including government, academia, education, research, industry and many others) and was very well attended. Over 650 delegates representing 69 countries from the aforementioned sectors participated. In fact, registration was closed two weeks prior to the commencement date, once the full holding capacity of the meeting rooms had been attained.

The regional aquaculture trends reviews and the global synthesis have already been published and are available at:
www.fao.org/fishery/regional-aquaculture-reviews/aquaculture-reviews-home/en

This publication comprises all other presentations and reviews of the Conference, which have been subject to peer review by a panel of experts. The Report of the Global Conference on Aquaculture 2010, which is available at the same site, provides a detailed account of the conduct of the Conference along with its technical recommendations.

As a modest step towards reassuring the support to sustainable aquaculture development, the Global Conference adopted the Phuket Consensus, a document which reaffirms commitment to implementing the Bangkok Declaration and Strategy which had been adopted during the Conference on Aquaculture in the Third Millennium held in 2000. The Phuket Consensus confirmed that the progress towards sustainable aquaculture development at the global level has been made possible largely by efforts made in line with the Bangkok Declaration and Strategy. The latter Strategy thus continues to be highly relevant to the aquaculture development needs and aspirations of FAO member countries; however, there are elements of the Bangkok Strategy that require further strengthening in order to enhance its effectiveness, achieve development goals and address persistent and emerging threats. The participants of the 2010 Global Conference therefore reaffirmed their commitment to the Bangkok Declaration and Strategy for Aquaculture Development and made several recommendations that since the early 1980s are outlined in the Phuket Consensus, as elicited at the end of this volume.

FAO and NACA have been collaborating on sustainable aquaculture development at the global level since the early 1980s, and significant contributions have been made jointly by FAO and NACA towards aquaculture development. With increasing poverty at the global level and the increasing demand for fish to feed a growing global population, much needs to be done to augment the contribution of aquaculture to global food and nutrition security. This volume, yet another joint effort of FAO and NACA, presents the much needed clear and comprehensive technical information that will assist in the mobilization of global efforts to alleviate poverty and improve food and nutrition security through sustainable and responsible aquaculture.

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From the Editors

We, the editors of *Farming the Waters for People and Food*, the Proceedings of the Global Conference on Aquaculture 2010, are delighted to acknowledge the completion of such a massive undertaking involved in compiling this volume. We thank the authors for their patience, continued support and assistance towards making this volume a success. We are grateful to the following FAO staff who assisted us in revising the manuscripts: Jose Aguillar-Manjarrez, Junning Cai, Alessandro Lovatelli, Melba Reantaso, Doris Soto and Koji Yamamoto. We sincerely thank Jose Luis Castilla Civit for his untiring efforts in layout design and page formatting.

Our challenge is to present to you an appealing, peer-reviewed, comprehensive scientific and technical document. We hope you will find that we have achieved this goal.

Unless otherwise mentioned, pictures used in this volume are the property of FAO.

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Part I – Keynote Addresses



Aquaculture and sustainable nutrition security in a warming planet

Keynote Address 1

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Abstract

According to World Food Summit 1996, food security exists when all people, at all times, have physical and economic access to enough safe and nutritious food to meet their dietary needs and food preferences for an active and healthy lifestyle. In order to be food secure, the food should be available and affordable. For the more than a billion people who do not get enough regular, healthy food, ill health and a shorter life expectancy are real risks. Children, and especially very young children, who suffer from food insecurity will be less developed than children of the same age who have had sufficient food. Aquaculture offers a significant opportunity for improving food security and nutrition by providing nutritious, yes affordable protein to many millions of people worldwide. The increase in global population, gradual depletion of finite resources required for sustainable expansion and development of aquaculture poses threats to future fish global protein supply. Over and above, the impacts of climate change are also posing threats to sustainable aquaculture development thus requiring focused implementation of mitigation and adaptation strategies. Current paper describes how aquaculture is perceived to contribute to improving food and nutrition security and the mitigations required for overcoming climate change and other environmental challenges for maintaining sustainability of the sector.

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KEY WORDS: *Aquaculture, climate change, global warming, sustainable nutrition security.*

Introduction

The most notable and significant changes associated with global warming are the gradual rise of global mean temperatures (Zwiers and Weaver, 2000) and a gradual increase in atmospheric green house gases (IPCC, 2007). Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. The process of global warming shows no signs of abating and is expected to bring about long-term changes in weather conditions (FAO, 2008). Eleven of the last 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850. According to the *United Nations Framework Convention on Climate Change*, the average temperature of the earth's surface has risen by 0.74 °C since the late 1800s and is expected to increase by another 1.8 to 4 °C by the year 2100. Global sea level rise, which has been occurring due to climate change, has accelerated since 1993. Mean sea-level has risen by about 0.1–0.2 mm/yr over the past 3 000 years and by 1–2 mm/yr since 1900, with a average value of 1.5 mm/yr. Some extreme weather events have changed in frequency and/or intensity over the last 50 years. More floods, hurricanes and irregular monsoons were experienced than in previous decades. Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. Some of the developing world's largest rivers are drying up because of climate change, threatening water supplies in some of the most populous places on earth. Many lakes, especially those in Africa have shown moderate to strong warming since the 1960s. The likelihood of wetlands completely drying out in dry seasons due to changes in temperature and precipitation is increasing. It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. Climate change will affect food production by raising temperatures, changing rainfall belts and increasing the variability of the weather with more frequent extreme events.

Issues on nutrition security in a changing green house gases (GHGs) scenario

Food security is an increasingly important issue for the rural communities who rely on agriculture to meet their subsistence needs. Malnutrition is still the number one killer compared to other diseases. The main indicators used to measure the extent of food insecurity are the numbers and proportions of all people estimated to be undernourished (i.e. without access to sufficient food to meet their energy requirements for an active life) and the numbers and proportions of infants who are considerably below the norms of height for their

age, weight for their height or weight for their age. Food security depends on the availability of food, its access and absorption.

The estimates show that that no less than 1.02 billion persons are currently undernourished. Undernourishment is overwhelmingly found in developing countries and is heavily concentrated in parts of Asia and in Africa south of the Sahara. Around two billion persons suffer from deficiencies in micronutrients, primarily of vitamin A, iodine and iron (UNSCN, 2004), making these the most common and often under-appreciated nutritional problems. In fact, many populations, those in developing countries more than those in developed ones, depend on fish as part of their daily diets. For them, fish and fishery products often represent an affordable source of animal protein that may not only be cheaper than other animal protein sources, but is preferred and a part of local and traditional recipes. In developing countries, a shift in diets towards more animal products will increase demand, and in industrialized countries, issues such as food safety and quality, environmental concerns and animal welfare will probably be more important than price and income changes.

Role of aquaculture in sustaining nutritional security

Food fish, whether captured or cultured, plays an important role in human nutrition and global food supply, particularly within the diets and food security of the poor. Food fish currently represents the major source of animal protein (contributing more than 25 percent of the total animal protein supply) for about 1 250 million people within 39 countries worldwide, including 19 sub-Saharan countries (FAO, 2009). Fish contributes more than 50 percent of protein intake for 400 million people from the poorest African and South Asian countries. Fish are important sources for many nutrients, including protein of very high quality, retinol (vitamin A), vitamin D, vitamin E, iodine and selenium. Evidence is increasing that the consumption of fish enhances brain development and learning in children, protects vision and eye health, and offers protection from cardiovascular disease and some cancers. The fats and fatty acids in fish, particularly the long chain n-3 fatty acids (n-3 polyunsaturated fatty acids (PUFAs)), are highly beneficial and difficult to obtain from other food sources. Of particular importance are eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic acid (22:6n-3, DHA).

Aquaculture production is playing an increasing role in meeting the demand for fish and other fishery products. The combined result of development in aquaculture worldwide and the expansion in global population is that the average annual per capita supply of food fish from aquaculture for human consumption has increased by ten times, from 0.7 kg in 1970 to 7.8 kg in 2008, at an average rate of 6.6 percent per year (FAO, 2010). The importance of aquaculture in meeting the protein requirements from fish is evident from the fact that while kilogram per capita fish consumption rose from 14.9 in 1995 to 17.1 in 2008, the percentage contribution increased from 29 to 46 percent for the same

period. Cultured food fish supplies currently account for nearly 50 percent of that consumed globally (FAO, 2009) and are targeted to increase to 60 percent by 2020 (FAO, 2008). With the improvements in culture practices, a more than six-fold increase in fish production and a four-fold increase in household fish consumption has occurred in Bangladesh (Gupta and Bhandari, 1999). Fish that command a good price (e.g. carps) will go to the market, whereas those that command a low price (e.g. tilapia) are used for household consumption (Dey *et al.*, 2000).

Status of capture and aquaculture fisheries production

Total fisheries production (capture fisheries and aquaculture) was about 142 million tonnes in 2008. Of this, 115 million tonnes was used as human food, providing an estimated apparent per capita supply of about 17 kg, which is an all-time high, and the remainder going to non-food uses (e.g. livestock feed, fishmeal for aquaculture). Aquaculture accounted for 46 percent of total food fish supply, representing a continuing increase from 43 percent in 2006. The global production of food fish from aquaculture, including finfish, crustaceans, molluscs and other aquatic animals for human consumption, reached 52.5 million tonnes in 2008. The contribution of aquaculture to the total production of capture fisheries and aquaculture continued to grow, rising from 34.5 percent in 2006 to 36.9 percent in 2008. In the period 1970–2008, the production of food fish from aquaculture increased at an average annual rate of 8.3 percent, while the world population grew at an average of 1.6 percent per year.

Aquaculture production using freshwater contributes 59.9 percent to world aquaculture production by quantity and 56.0 percent by value. Aquaculture using seawater (in the sea and also in ponds) accounts for 32.3 percent of world aquaculture production by quantity and 30.7 percent by value. Although brackishwater production represented only 7.7 percent of world production in 2008, it accounted for 13.3 percent of total value, reflecting the prominence of relatively high-valued crustaceans and finfishes cultured in brackishwater. Although cultured crustaceans still account for less than half of the total crustacean global production, the culture production of penaeids (shrimps and prawns) in 2008 was 73.3 percent of the total production. The introduction of whiteleg shrimp (*Litopenaeus vannamei*) to Asia has given rise to a boom in the farming of this species in China, Thailand, Indonesia and Viet Nam in the last decade, resulting in an almost complete shift from the native giant tiger prawn (*Penaeus monodon*) to this introduced species in Southeast Asia. The ban on the introduction and culture of whiteleg shrimp was lifted in 2008 in India, and this will have a major impact on the country's shrimp farming sector in the years to come.

Synthesis of the trends in aquaculture production, at five year intervals, for each of the cultured commodities (*vis-à-vis* finfish, molluscs, crustaceans and seaweeds), based on FAO Statistics (FAO, 2008) for three climatic regimes, viz.

tropical (23 °N to 23 °S), subtropical (24–40 °N and 24–40 °S) and temperate (>40 °N and >40 °S) revealed that production in the tropics accounted for more than 50 percent, the highest being for crustaceans, which approximated 70 percent. In Asia, irrespective of climate regime, the contribution of aquaculture to total fish production has been increasing over the last two decades, a trend that has been observed in many of the current major aquaculture-producing countries on that continent (De Silva, 2007).

Impact of climate change scenarios and concerns for aquaculture

Vulnerability to the impacts of climate change is a function of exposure to climate variables, sensitivity to those variables and the adaptive capacity of the affected community. Often, the poor are dependent on economic activities that are sensitive to the climate. To determine which among the fisheries of 132 nations were the most vulnerable, 33 countries were rated as “highly vulnerable” to the effects of global warming on fisheries. These countries produce 20 percent of the world’s fish exports and 22 are already classified by the United Nations as “least developed”. Inhabitants of vulnerable countries are also more dependent on fish for protein. Two-thirds of the most vulnerable nations identified are in tropical Africa. The thriving catfish farming in the Mekong Delta, Viet Nam (a highly vulnerable country) that provides 150 000 livelihoods with a production of 1 million tonnes valued at USD1 billion per year, would be jeopardized by saline intrusion due to sea level rise. African countries which depend greatly on fish for protein and have the least capacity to adapt to climate change are semi-arid with significant coastal or inland fisheries, i.e. higher vulnerability to future increases in temperature and linked changes in rainfall, hydrology and coastal currents. Island nations and others like Bangladesh would be greatly hit by the increase in frequency and intensity of storms and resulting flooding.

Drivers of climate change

Climate change impacts may be significant at a number of different scales ranging from global down to the local community level. By combining national or global-level indicators with case studies at the district or local community level, it may be possible to highlight and better understand a broader range of impacts (O’Brien *et al.*, 2004). For example, while a large area may be exposed to the risk of flooding or drought, the adaptive capacity of different communities within that area may vary greatly.

Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be the most significant drivers of climate change in inland aquaculture. Reduced annual rainfall, dry season rainfall and the resulting growing season length are likely to create impacts for aquaculture and could lead to conflict with other agricultural, industrial and domestic users in water-scarce areas. Mean air temperature will not necessarily equate to

increases seen in the temperature of aquaculture pond waters. The main climatic factors influencing the water temperature in an inland environment are solar radiation, air temperature, wind speed and humidity, in combination with the pond shape and size and its water levels. Turbidity and water colour also influence the amount of solar radiation absorbed. As aquaculture ponds are typically shallow and turbid, solar radiation is likely to be an important influence on temperature (Kutty, 1987). A change in temperature of only a few degrees might mean the difference between a successful aquaculture venture and an unsuccessful one (Pittock, 2003). Any increase in the intensity and/or frequency of extreme climatic events can damage aquaculture. The first and second assessment reports on ocean systems (Tsyban, Everett and Titus, 1990; Ittekkot *et al.*, 1996) conclude that global warming will affect the oceans through changes in sea-surface temperature (SST), ice cover, ocean circulation and wave climate, which affect the ocean productivity, which indirectly affects aquaculture.

Ecological, physical and socio-economic impacts

The changes in drivers of climate change will in turn create physiological (e.g. growth, development, reproduction, disease), ecological (e.g. organic and inorganic cycles, predation, ecosystem services) and operational (e.g. species selection, site selection) changes. Increased precipitation can bring its own problems in the form of flooding. Floods may damage facilities, cause stock to escape, affect salinity and introduce predators or disease. Increase in monsoon intensity has been predicted over some Asian regions, while changes in the timing of the monsoon pattern and increased interannual variability could also be significant (Mirza *et al.*, 2001; Mirza, 2002). Sea level rise will have gradual impacts due to loss of land via inundation and erosion. Areas such as mangroves and salt marshes, which act as nursery grounds supplying seed for many aquaculture species and provide some coastal protection, may be lost as they are sandwiched between the rising sea and developed land behind them. Salinization of ground water may occur, especially in low-lying areas, reducing the availability of freshwater for aquaculture and other uses.

Precipitation

Variability in the amount of precipitation under different scenarios of monsoon could negatively impact aquaculture. Delay in onset of monsoon leads to high salinity build up, especially in low tidal amplitude areas, and conflict with other users for using freshwater to dilute high salinity. High rainfall resulted in a rapid drop in salinity to levels that were lethal for kuruma prawn (*Marsupenaus japonicus*), causing mass mortality of the farm crop (Preston *et al.*, 2001). The impacts are likely to be felt most strongly by the poorest aquaculturists, whose typically smaller ponds go dry more quickly and who may suffer from shortened growing seasons, reduced harvests and a narrower choice of species for culture. Algal blooms, depletion of dissolved oxygen and consequent production losses in inland and coastal ponds may occur, particularly in summer months when water exchange becomes difficult. Changes in suspended sediment and nutrient loads

resulting from altered rainfall patterns will affect aquaculture ponds. Elevated nutrient levels can stimulate algal blooms containing toxins that accumulate in oysters, posing a threat to public health (Nell, 1993).

Temperature

The negative impacts of higher water temperatures in inland waterbodies include deteriorated water quality, worsened dry season mortality, introduction of new predators and pathogens, and changes in the abundance of food available to fishery species. If the temperature rise causes increase in metabolic rates of aquatic species greater than the increase in food supply, then there will be a negative impact on growth performance. Increased water temperatures and other associated physical changes such as shifts in dissolved oxygen levels have been linked to increases in the intensity and frequency of disease outbreaks (Goggin and Lester, 1995; Harvell *et al.*, 2002; Vilchis *et al.*, 2005) and more frequent algal blooms in coastal areas (Kent and Poppe, 1998). Water temperature also can have a direct effect on survival of larvae and juveniles, as well as on growth of aquatic organisms, by acting on physiological processes. Changes in temperature would change plankton community structure. Dinoflagellates have advanced their seasonal peak in response to warming, while diatoms have shown no consistent pattern of change (Edwards and Richardson, 2004). Temperature changes will have an impact on the suitability of species for a given location. Since fish are poikilothermic, climate changes will significantly alter their metabolism, resulting in reduced growth rate and total production, increased vulnerability to disease and changes to reproduction seasonality. Hence, increase in temperature due to climate change will have a much stronger impact on aquaculture productivity and yields.

Consequent lengthening of the growing season for cultured fish and shellfish and increased production of aquaculture species by expanding their range are positive impacts of high temperatures in mid to high latitudes. In cooler zones, aquaculture may also benefit, as rising temperatures could bring the advantage of faster growth rates and longer growing seasons. Raised metabolic rates increase feeding rates and growth if water quality, dissolved oxygen levels and food supply are adequate, a possible benefit for aquaculture, especially for intensive and semi-intensive pond systems. McCauley and Beitinger (1992) predict that for every 1 °C rise in temperature, the optimum range for the culture of channel catfish (*Ictalurus punctatus*) will shift approximately 240 km north. A simple linear growth model of roho labeo (*Labeo rohita*) fingerlings provides a reliable projection of growth with unit rise of temperature within the range of 29 to 34 °C. In fish farm hatcheries on the gangetic plains in West Bengal, a positive impact on breeding was observed in the advancement and extension of the breeding period of Indian major carps by 45–60 days. Almost all fishers and operators of fish hatcheries indicated that rise in temperature is the main reason for advancement of the breeding season of Indian major carps, along with the increasing demand and high price of seed early in the season.

Extreme climatic events

Cyclones and floods can cause damage to infrastructure, inundation of ponds and loss of stock (Ponniah and Muralidhar, 2009; Muralidhar *et al.*, 2009). Changes in salinity of pond water would result in yield reduction and the introduction of disease or predators into aquaculture facilities along with the flooded water, resulting in crop losses and impacts on wild fish recruitment and stocks in the waterbodies. Drought also had a great impact on aquaculture, and rise in salinity in the waterways will leads to drop in the culture area. Since climate change is expected to affect the availability of freshwater and the flow in rivers, it is essential to forecast the water availability for aquaculture. The potential increase in flood frequency, intensity and duration may have negative consequences for aquaculture in terms of loss of stock and damage to aquaculture facilities (Handisyde *et al.*, 2006).

Sea level rise

Sea level rise (SLR) leads to loss of land due to inundation and would lead to reduced area available for aquaculture, loss of freshwater fisheries and aquaculture due to reduced freshwater availability, changes in estuary systems and shifts in species abundance and the distribution and composition of fish stocks and aquaculture seed. Seawater intrusion into freshwater aquifers is an increasing problem with rising sea level (Moore, 1999). Higher sea levels may make groundwater more saline, harming freshwater fisheries, freshwater aquaculture and agriculture, and causing loss of coastal ecosystems such as mangroves and salt marshes, which are essential to maintaining wild fish stocks as well as supplying seed to aquaculture.

Aquaculture diversification due to a shift to brackishwater species resulting from reduced freshwater availability is a possibility. Increased areas might be suitable for the brackishwater culture of high-value species such as shrimp and mud crab. About 829 ha of seawater inundated areas in the Andaman and Nicobar Islands are suitable for brackishwater aquaculture after the 2004 tsunami (Pillai and Muralidhar, 2006). Increase in inland salinization in Bangladesh may have serious impacts on agriculture, with a 0.5 million tonne reduction in rice production predicted in association with a 0.3 m sea level rise. It is possible that culture of brackishwater species in these affected areas may be able to provide alternative sources of income and nutrition. A one meter sea level rise in the Mekong Delta is predicted to inundate 15 000 to 20 000 km², with a loss of 76 percent of arable land. Sea level rise and reduced river flows are causing increased saltwater intrusion in the Mekong Delta, threatening the viability of catfish aquaculture. Such culture areas must be shifted further upstream to mitigate climatic change effects. On the other hand, climate impacts could make extra pond space available for shrimp farming (De Silva and Soto, 2009). It is predicted that the future sea level rise along the 1 030 km long Andhra Pradesh coast in India will place the 43 percent (442.4 km) of coastal area that is very low-lying under very high risk. If the sea level rises by 0.59 m as predicted by

IPCC (2007), an area of about 565 km² would be submerged under the new low-tide level along the entire Andhra Pradesh coast, of which 150 km² would be in the Krishna-Godavari delta region alone, affecting the livelihoods of hut-dwelling fishing communities and small-scale aquaculturists (Nageswara Rao *et al.*, 2008).

Oceanographic variables

Aquaculture depends heavily on capture fisheries for fishmeal and in certain areas, for seed and hence, there is an urgent need to find plant protein-based alternatives to fishmeal and to domesticate species for which there is still a dependence on wild broodstock. Climate change could have dramatic impacts on fish production which would affect the supply of fishmeal and fish oil. Tacon, Hasan and Subasinghe (2006) estimated that in 2003, the aquaculture sector consumed 2.94 million tonnes of fishmeal globally (53.2 percent of global fishmeal production), considered to be equivalent to the consumption of 14.95 to 18.69 million tonnes of forage fish/trash fish/low-value fish, primarily small pelagics. The potential for adverse impacts of climate change on global fishmeal production is well illustrated by periodic shortages associated with climate fluctuations such as El Niño. Expansion of aquaculture industries is placing increasing demand on global supplies of wild-harvest fishmeal to provide protein and oil ingredients for aqua-feeds. About 30 percent (29.5 million tonnes) of the world fish catch is used for non-human consumption, including the production of fishmeal and fish oil that is employed in agriculture, in aquaculture and for industrial purposes. Depending on the species being cultured, they may constitute more than 50 percent of the feed.

Building climate-resilient aquaculture

Climate change is likely to be a powerful driver of change, and it has to be accepted that humans cannot control ecosystems and that social-ecological stability is the exception rather than the norm. To cope with climate change that is likely to be both rapid and unpredictable, aquaculture systems must be resilient and able to adapt to change. Resilient aquaculture systems are those that are more likely to maintain economic, ecological and social benefits in the face of dramatic exogenous changes such as climate change and price swings. Resilience requires genetic and species diversity, low stress from other factors, and “healthy” and productive populations. Effective ecosystem approach to aquaculture (EAA) should lead to resilient social-ecological systems. In the face of uncertainty, aquaculture food production systems should be established which are diverse and relatively flexible, with integration and coordination of livestock and crop production.

Aquaculture is the best adaptation of fisheries to climate change, due to its ability to respond to demand, improve efficiency of resource use and overcome disease shocks. Improving efficiency of resource use is mainly through improved

feeding technology, diet formulation, conversion and integration on a global scale, and zero exchange systems, recirculation systems, integration with irrigation and intensification (e.g. striped catfish, *Pangasianodon hypophthalmus*, production of up to 300 tonnes/ha in Viet Nam). Aquaculture's ability to respond to disease shocks is through better site selection and vaccines in salmon, use of low and zero water exchange systems, the selective breeding of disease-free and disease resistant stocks in shrimp, and the introduction of new species in oysters.

Farming systems and diversification in fresh and brackishwater

Increasing investment in aquaculture and aquatic ecosystems is an investment in the “liquid assets” of adaptation. Aquatic ecosystems play a crucial role in buffering and distributing climatic shocks, whether from storms, floods, coastal erosion or drought. Aquaculture provides opportunities to adapt to climate change by integrating aquaculture and agriculture, which can help farmers cope with drought while increasing livelihood options and household nutrition. Water from aquaculture ponds can help sustain crops during periods of drought while at the same time, the nutrient-rich waters can increase productivity. Farmers can use saline areas no longer suitable for crops (expected to increase due to sea level rise) to cultivate fish. The impacts on small-scale farmers and commercial-scale large farmers may be different. For example, for small-scale farmers, providing food and/or income at the household or community level may be seriously affected by an extreme event such as a flood, which may result in an immediate reduction in the availability of food and money. Small-scale farmers may not have sufficient financial resources to overcome these situations.

The integration of aquaculture, fisheries, agriculture and other productive or ecosystem management activities has an integral role to play in the future of the aquaculture industry. The techniques include ranching, integrated agriculture-aquaculture (IAA), integrated multitrophic aquaculture (IMTA) and links with renewable energy projects. Integration is a key element of the ecosystem approach to aquaculture (EAA), which “is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems” (Soto *et al.*, 2008). Trends include the expansion of the farming of low-trophic-level fish, the culture of more efficient shrimp species (i.e. *Litopenaeus vannamei* vs *Penaeus monodon*), more efficient feed conversion, lower protein and fishmeal content in diet, use of zero water exchange systems, closed breeding cycles, domesticated specific pathogen free (SPF) and specific pathogen resistant (SPR) stocks, and the more efficient use of fishmeal and fish oil inputs.

Improved planning and management of current aquaculture areas will be achieved through enforcement of aquaculture waste-treatment regulations, the introduction of aquaculture species adapted to high temperatures and changed salinities, the promotion of polyculture and fish-rice rotation in relevant areas, and the use of integrated water management for rice agriculture and

brackishwater aquaculture. Assessment of new species and the tools and techniques needed by fishers to adapt to changed aquatic habitats due to increases and fluctuations in salinity levels in estuaries will be needed. IMTA, a practice in which the by-products (wastes) from one species are recycled to become inputs (fertilizers, food) for another, will be increasingly implemented.

Water management

Although global trade and technological innovation are key drivers in providing stable and resilient global systems, the most destabilizing global water-related threat is increasing food prices and hunger. Water is becoming increasingly scarce in some parts of the world. Most of the freshwater used by humans goes to irrigation. There will be increasing pressure to use that water for human and industrial uses. Moreover, some groundwater aquifers are being overdrawn, calling into question the long-term sustainability of current levels of irrigation. Water scarcity may thus either restrict production or increase its cost. Aquaculture will have to compete with agriculture as well as industrial and domestic users for a limited water supply which may often be supporting a growing population. The relative value of aquaculture products in relation to non-fish alternatives will be significant, as well as the productivity of capture fisheries (Brugère and Ridler, 2004). Water stress due to decreased precipitation and/or increased evaporation may limit aquaculture in some areas. This may take the form of increased risks associated with a reduced water supply on a continual basis, or by reducing the length of a routine growing season. Increased variation in precipitation patterns and droughts may increase the risk and costs of aquaculture in some areas as provision for these extremes has to be made.

Low external input sustainable aquaculture – organic farming

Organic aquaculture has attracted the attention of consumers, environmental advocates and entrepreneurial innovators. It reduces overall exposure to toxic chemicals from pesticides that can accumulate in the ground, air, water and food supply, thereby lessening health risks for consumers. Some of its other merits include curbing top soil erosion, improving soil fertility, protecting groundwater and saving energy. Moreover, organic standards prohibit the use of genetic engineering in production, which again reassures consumers. The growing interest in organic aquaculture has prompted governments to regulate the sector. Standards and certification procedures are being developed and tested. They are the necessary tools to promote investment. In the absence of international standards, interested parties are developing their own specific organic aquaculture standards and accreditation bodies. These standards often vary significantly from place to place, certifier to certifier, and species to species.

Ecosystem approach to aquaculture

The ecosystem approach to aquaculture (EAA) is the mechanism to attain sustainable development in aquaculture through stressing holistic, integrated and participatory processes. None of the principles that underlie the EAA are

new; they can all be traced in earlier instruments, agreements and declarations. The EAA pulls them together formally as tools for the effective implementation of the *Code of Conduct for Responsible Fisheries* (FAO, 1995). The basic objectives of EAA are maintaining ecosystem integrity/ecological well-being, improving human well-being and equity promoting and enabling good governance. In practice, the key features of EAA are applying precautionary approaches, using best available knowledge, acknowledging the multiple objectives and values of ecosystem services, embracing adaptive management, broadening stakeholder participation, understanding and using a full suite of management measures, and promoting sectoral integration.

EAA addresses adaptation through creating resilient communities (ecosystem, human, governance), decreasing vulnerability (impacts, adaptive capacity, sensitivity), enhancing intersectoral collaboration (e.g. integrating fisheries into national adaptation and disaster risk management (DRM) strategies), promoting context-specific and community-based adaptation strategies, allowing for quick adaptation to change, and promoting natural barriers and defences. It addresses mitigation (increased sequestration and decreased emissions) through understanding the role of aquatic systems as natural carbon sinks, supporting a move to environmentally friendly and fuel-efficient fishing practices (harvest and post-harvest) and governance/responsible practices, eliminating subsidies that promote overfishing and excess capacity. Mitigation and adaptation together are addressed through safeguarding the aquatic environment and its resources against adverse impacts of mitigation strategies and measures from other sectors, avoiding maladaptation and benefiting from win-win synergies.

Breeding for climate change

Taking advantage of their short generation time and high fecundity, it would be possible to selectively breed fishes to tolerate the higher temperature, salinity and increased diseases that are likely to impact aquaculture due to climate change. Despite significant increase in a wide range of physiological information available on the link between environmental stress and some indicators of host response, the influence of different abiotic stressors on gene expression has been understudied. The research should focus on the evolution of physiological and genetic adaptations to osmotic and thermal stress in aquatic animals. Biologists typically work on one trait at a time (e.g. aspects of drought tolerance). With simultaneous changes in temperature, precipitation and pathogen dynamics, the breeding challenge will be enormous. The molecular and mechanistic basis of the osmotic stress response and how it relates to other environmental stress responses have to be understood. Drought, thermal and salinity tolerance, and resistance to disease are traits that need to be engineered into aquatic species for climate change adaptations.

Selection for species with effective thermoregulatory control will be needed. Integrated research will be needed in the broader field of species improvement

and in assessments of the production chain from geneticists to consumers. Breeding technologies have been successful in developing hormonal sex-reversal in tilapia, genetically male tilapia, hormone induced spawning in *Pangasianodon*, triploid oysters and selective breeding for disease resistance. Genetic engineering was developed to develop genetically modified (GM) feed ingredients (e.g. soya, rapeseed (canola) oil), and aquaculture species (e.g. salmon, tilapia).

Mangroves – bioshield against sea level rise

Nature has provided biological mechanisms for protecting coastal communities from the fury of cyclones, coastal storms, tidal waves and tsunamis. Mangrove forests constitute one such mechanism for safeguarding concurrently the ecological security of the coastal areas and the livelihood security of fisher and farm families living in the coastal zone. Mangrove forest establishes in coastal areas where river water mixes with seawater. These areas are called estuarine or brackishwater coastal zone environments. Mangrove forests located in the estuarine environment are intersected by a number of small creeks and channels and in many cases, large open waterbodies are also found associated with them. Mangrove forests and associated tidal creeks, channels and lagoons together constitute mangrove wetlands. These mangrove wetlands mitigate the adverse impact of storms, cyclones and tsunamis in coastal areas; reduce coastal erosion and on the other hand, provide gains to land by accreting sea and adjacent coastal waterbodies. They also function as breeding, nursery and feeding grounds for many commercially important crustaceans, fish and molluscs and enhance the fishery potential of adjacent coastal waters by providing them with large quantities of organic and inorganic nutrients. The 26 December 2004 tsunami has created a widespread interest in the restoration of degraded mangrove forests, the promotion of joint mangrove management systems involving local communities, and the raising of bio-shields and shelterbelts along the coastal zone.

Planned adaptation measures – early warning systems and others

In the context of climate change, the primary challenge to the fisheries and aquaculture sector will be to ensure food supply, enhance nutritional security, improve livelihoods and economic output, and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change, evolving adaptive mechanisms and implementing actions across all stakeholders at the national, regional and international levels. Adapting to climate change involves reducing exposure and sensitivity and increasing adaptive capacity. Projections on climate change impact on aquaculture need to be developed as the first step for future analytical and empirical models, and for planning better management adaptations. Governments should consider establishing weather watch groups and decision support systems on a regional basis. Specific policy documents with reference to the implications of climate change for aquaculture need to be developed. These documents should take

into account all relevant social, economic and environmental policies and actions, including education, training and public awareness related to climate change. Effort is also required in respect of raising awareness of the impacts, vulnerability, adaptations and mitigation related to climate change among the decision-makers, managers, aquaculturists and other stakeholders in the aquaculture sector (Muralidhar *et al.*, 2010). It is necessary to increase awareness on the potential to develop adaptive livelihoods, improve governance and build institutions that can help people and integrate aquaculture into overall climate change and rural development policies.

Trends in fish culture in a warming planet may affect the nutrition and livelihood security of the poor. Poor people are vulnerable to many events and factors that create poverty, wherein it is very difficult to improve livelihoods. They are generally hardly aware of adaptive strategies and potential solutions in these situations. Strategies to promote sustainability and improve supplies should be in place before the threat of climate change assumes greater proportion. While the aquaculture sector contributes little to greenhouse gas emission, it could contribute to reducing the impacts by following effective adaptation measures. Mitigation strategies should primarily address global energy policy. Investigation into whether there is potential for low-cost, effective sequestration of GHGs by aquacultural systems should be supported. Much further research is needed to better understand the complex impacts of climate change on aquaculture and to devise coping strategies. Fisheries and aquaculture make a minor but significant contribution to greenhouse gas emissions during fishing operations and the transport, processing and storage of fish; compared to actual fishing operations, the emissions per kilogram of postharvest aquatic product transported by air are quite high. Intercontinental airfreight emits 8.5 kg of CO₂ per kilogram of fish transported. This is about 3.5 times that for sea freight and more than 90 times that from local transportation of fish where it is consumed within 400 km of capture.

Conclusions

Action is urgently needed to mitigate the factors driving climate change, as well as to adopt adaptive measures aimed at countering the threats to food and livelihood provision. In addition to laws, regulations and voluntary codes of practice that aim to ensure environmental integrity, some of the means of achieving the environmental and social responsibility goals include innovative, less-polluting production techniques such as those based on the EAA. In this regard, tools and indicators have to be developed for the purpose of assessing and monitoring not only the impacts of aquaculture on the environment, but also the impacts of the environment on aquaculture and site selection. In terms of improving social responsibility, governments are defining minimum wages, improved labour conditions, worker welfare systems, etc. which are being embraced by many lobbyists. Certification systems for aquaculture practices and

products are beginning to include standards for monitoring social responsibility and equity. If we practice “green aquaculture”, we can achieve the goal of “fish for all and forever”.

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Global aquaculture development since 2000: progress made in implementing the Bangkok Declaration and strategy for aquaculture development beyond 2000

Keynote Address 2

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Abstract

At the *Conference on Aquaculture in the Third Millennium* held in Bangkok in February 2000, participants agreed on a global strategy towards achieving the social, economic and environmental sustainability goals of aquaculture development. The *Bangkok Declaration and Strategy for Aquaculture Development beyond 2000* was a watershed, occurring as it did at the turn of the millennium and creating major influences on the development of aquaculture in the decade since. This presentation briefly traces the progress of the sector during the decade that has passed since the Millennium Conference and discusses some encouraging and important historical developments that have shaped today's aquaculture sector. The Millennium Conference identified 17 key elements to a sustainable aquaculture development and recommended that states incorporate these into their strategies for aquaculture development. Each of the key elements is briefly discussed to provide an overview of the progress that was made over the past ten years in implementing the Declaration. Given the impressive growth that the sector has achieved in the past three decades, aquaculture is gradually

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being recognized for its contributions to food security, poverty reduction, rural development and economic growth. The Bangkok Declaration and Strategy will continue to guide the sector's development and management beyond 2010 through to the first quarter of this century. However, there are elements of the Strategy that require further strengthening in order to enhance its effectiveness, to achieve development goals and to address persistent and emerging threats. By endorsing the draft Phuket Consensus, Conference participants will re-affirm their commitment to the *Bangkok Declaration and Strategy for Aquaculture Development* and will recommend some new actions.

KEY WORDS: *Aquaculture, Bangkok Declaration and Strategy, Development, Global trends, Sustainable aquaculture.*

Introduction

Dear Friends,

You have heard from Professor Swaminathan on the value and importance of aquaculture as a global food production sector. I would like to focus my talk on “aquaculture’s road to success”. An important measure of success is the way the governance of the sector has contributed to uplifting the welfare of the small-scale, non-commercial and family-based farms from which aquaculture began, and to promoting the growth of the large commercial and industrial operations. I will also trace the progress of the sector during the decade that has passed since the global *Conference on Aquaculture in the Third Millennium* in 2000. In doing so, let me first briefly share with you some encouraging and important historical developments that have shaped today’s aquaculture sector.

Since Fan Li described carp culture in earthen ponds in China in the fifth century B.C., the culture of carps has made a massive contribution to most parts of the world, providing rapidly growing populations with cheap protein. Through time, farmers of such a system have preserved its best feature: farming within the limits of nature. As the demand for fish increased, the need to build aquaculture into a fully fledged industry was felt; the first world meeting on aquaculture, *The World Symposium on Warm-water Pond Fish Culture*, was organized by the Food and Agriculture Organization of the United Nations (FAO) in May 1966 in Rome. The Symposium seeded the idea of a global conference and ten years later, the *FAO Technical Conference on Aquaculture* was held in Kyoto (from 26 May to 02 June 1976). It is widely seen as the major turning point in the development of aquaculture.

The Kyoto Conference reviewed the status, problems, opportunities and potential for the culture of fish, crustaceans, molluscs and seaweeds and issued the *Kyoto Declaration on Aquaculture* that inspired what became known as the *Kyoto Strategy for Aquaculture Development*. The Kyoto Strategy placed aquaculture prominently in national planning. The young sector thus became recognized as

a legitimate user of land and water resources, and worthy of more research investment. Personnel were trained for better planning, management, research and production. The technological component of the Kyoto Declaration boosted productivity.

In the 1980s, aquaculture began to outpace all other food production sectors. Both small-scale farms and commercial operations, supported by an increasingly efficient global trade regime and marketing network, contributed to the success of the sector. But to feed a growing world, it had to push beyond the constraints imposed by nature, at times disorderly and with little restraint. In the late 1980s, it began to show this tendency, subsequently suffering from its unfortunate effects, which included pollution, disease and social disapproval. To bring order to its development and that of fisheries as a whole, FAO and its Member Governments, in 1995, promulgated the *Code of Conduct for Responsible Fisheries*. The Code, which enshrined the principles of environmental and social responsibility, became a major guide for the more effective governance of aquaculture. Those who wanted to farm in accordance with the Code's principles were assisted through the drafting of technical guides, standards and certification schemes. Ensuring social and environmental responsibility made the sector busy.

Going into the third millennium, the sector saw the need to develop a comprehensive working strategy. At the *Conference on Aquaculture in the Third Millennium* held in Bangkok in February 2000, participants agreed on a global strategy towards achieving the social, economic and environmental sustainability goals of aquaculture development. The *Bangkok Declaration and Strategy for Aquaculture Development beyond 2000* was a watershed, occurring as it did at the turn of the millennium and creating major influences on the development of aquaculture in the decade since. Soon after the Millennium Conference, the FAO Committee on Fisheries (COFI) Sub-Committee on Aquaculture was established. It is the only global intergovernmental forum with a mandate to discuss aquaculture issues. It serves as an international forum for consultation and discussion on technical and policy matters that would make aquaculture contribute in a sustainable way to food security, economic development and poverty alleviation. Its creation gave a powerful impetus to the Bangkok Declaration and Strategy.

Progress towards meeting the key elements of the millennium conference

The Millennium Conference identified 17 key elements to a sustainable aquaculture development and recommended that states incorporate these into their strategies for aquaculture development. Let me take you through each element of the Declaration to provide an overview of how much progress was made over the past ten years in implementing the Declaration. During

the Conference, we will hear more on progress and improvements for further development of the aquaculture sector.

Investing in people through education and training

Aquaculture has moved from a traditional to a professional sector. The levels of education and technology have leaped over the past decades, with a great deal of changes and improvements to capacity and skills development, both formal and vocational. The progress is worldwide, the sector evolving from an unskilled to a skilled work force involving various disciplines, including biology, economics, engineering, nutrition, social science, technology and recently, veterinary medicine.

Investing in research and development

Advancement in research in aquaculture is significant. Design innovations leading to sophisticated and environmentally sound recirculation systems and to fully automated submerged commercial sea-cage systems are now in use for commercial production. We have produced aquafeeds with much reduced fishmeal contents with little or no impairment of growth rates. There are many more examples that could be given; however, we still need to continue infusing science into the sector. More work is needed. These issues will be discussed in the thematic reviews of this Conference.

Improving information and communication

Information and communication, particularly by virtual means, has improved tremendously. The sector harnessed new technologies in many ways. Many initiatives such as the World Wide Web, virtual networks, interactive videos and hard-copy publications have emerged, providing effective mechanisms for access to relevant and reliable information for all stakeholders. When I searched “aquaculture information” in Google on 09 September, 478 000 results appeared in one-third of a second!

Improving food security and alleviating poverty

Many governments recognized aquaculture as a means of food security and poverty alleviation. People-centered development became one of the points of emphasis of aquaculture policy. Aquaculture found its place in the national poverty reduction sector papers of many developing countries. Programmes focusing on empowering small-scale farmers have been initiated. The discourse on whether or not aquaculture can reduce extreme poverty continues, but there is no doubt that aquaculture contributes to improving food security and the livelihoods of millions.

Improving environmental sustainability

Environmental impacts received a high degree of attention in the past decade, typically in cases where the welfare of society was negatively affected by unregulated aquaculture development. Public pressure and continued

commercial expansion compelled the sector to mitigate its environmental impacts. Governments began to recognize that well-planned and well-managed aquaculture can yield a net social benefit because, among others, the environment is not degraded. Continuing improvements, interventions and investments are required to ensure a higher degree of environmental sustainability and economic viability in the sector as pressures on the natural resource base and public awareness of environmental issues continue to build up. A new paradigm in aquaculture management, the ecosystem approach, can better reconcile the human and environmental objectives of sustainable development.

Integrating aquaculture into rural development

Providing employment to some 30 million persons, aquaculture contributes significantly to the rural development of many developing countries. As aquaculture moved from a traditional activity to a profit-seeking commercial venture, many countries recognized its role in rural development and created conducive policy environments for its expansion. This has provided governments with guidelines to better allocate resources, helping in the more effective use of resources and in mitigating the impacts of aquaculture on society. Aquaculture development was thus elevated into aquaculture for rural development.

Investing in aquaculture development

Globally, investment in aquaculture has increased. Aquaculture is slowly changing from a traditional, small-scale activity to a more commercial sector. There is increasing investment from the private sector, good evidence not only of aquaculture's profitability, but also of its improved governance, the private sector being assured that its investments are protected. This has attracted local and foreign direct investments. Some countries have diversified their foreign investment to include aquaculture. Most investment has long-term strategies to ensure sustainability. However, the public investment into aquaculture – particularly in research and development (R&D) support and institutional services – has been lagging behind during the past decade.

Strengthening institutional support

It is difficult to assess if major improvements in institutional support to aquaculture took place during the past decade. However, we do have some evidence of national aquaculture policies, strategies and plans being developed in several countries in regions such as Southeast Asia, Central Asia, Africa and the Pacific. Institutional strengthening programmes have also been initiated by a number of countries. In general, state-run extension services have been down-sized and legal frameworks for international trade in aquatic products have been strengthened. There is much to be done to strengthen institutional support to enable the public sector to provide the essential services needed to address various aspects of aquaculture development, in particular those affecting small-scale producers.

Applying innovations in aquaculture

There have been notable innovative ideas and technologies in aquaculture, from farmer innovations and the relevant application of indigenous knowledge to cutting edge technologies developed by or for the industrial, commercial sector. For example, an old Chinese concept, “multitrophic aquaculture” has been revitalized in many countries to improve productivity while reducing negative impacts on the environment through nutrient stripping.

Improving culture-based fisheries and enhancements

The huge potential of culture-based fisheries and enhancements for increasing fish supplies from freshwater and marine fisheries and generating income in inland and coastal areas is clear. However, while our understanding of how culture-based fisheries and enhancements can contribute to rural development and food security has increased during the past ten years, the aquaculture sector needs to make a much more concerted effort to match their vast potential.

Managing aquatic animal health

We have seen many improvements in all aspects of aquatic animal health. The aquaculture sector has acquired a better understanding of the aetiology and epidemiology of diseases. Diagnostic methods for clinical and veterinary medicine have been adapted for aquaculture, and various products (e.g. vaccines, immunostimulants and rapid diagnostic kits) are now available in the market. Producers in many countries have remarkably improved their husbandry practices, and there is now greater involvement of veterinary practitioners. Institutional, policy and regulatory aspects have been improved in many places, including cooperation between aquaculture and veterinary authorities. Some epizootics occurred, such as infectious salmon anaemia (ISA) in Chile, koi herpes virus (KHV) in many countries and epizootic ulcerative syndrome (EUS) in southern Africa. However, in general, we now have much better disease intelligence, improved emergency response and disease risk management capacities. We will likely see nanotechnology being used, and aquatic animal health will be fused into the “one health” concept of a healthy animal, people and ecosystem.

Improving nutrition in aquaculture

The past decade saw many positive developments in aquaculture feeds and nutrition. Much progress was made in the substitution of the essential amino acids and other nutrients derived from fishmeal by the use of plant material. However, the debate as to whether it is ethical to feed carnivorous species with “vegetarian” diets has been added to the old debate over feeding fish with fish. Although overall feed management has been improved, fishmeal substitution has been effective and several major species have shown better feed conversion ratios (FCRs); substitution of fish oil continues to be considerably more problematic. Some untapped resources such as marine invertebrates may become an alternative source to fishmeal and oil.

Applying genetics to aquaculture

The bulk of aquaculture production still comes from wild or recently domesticated stocks. The genetic management and hatchery procedures for these species have generally not been adequate and systematic, including in some developed countries. This has apparently degraded the performance of many farmed species through inbreeding, genetic drift and uncontrolled hybridization. In contrast, properly managed selective breeding programmes have shown continual improvements in performance and quality. Using induced triploidy, large rainbow trout which continue to grow and remain in prime condition have been developed, while the technology has also been widely used for the production of “all-year-round” oysters. Transgenic technology has been applied to a number of fish species in recent years, although restricted to research. However, there is a high level of public concern about genetic modification (GM) technology, and the widespread adoption of transgenic fish for a single trait such as growth performance, even if it were licensed, could encounter consumer resistance.

Applying biotechnology

Biotechnology has a wide range of useful applications in fisheries and aquaculture. It brings opportunities, for instance, to increase growth rates in farmed species, boost the nutritional value of feed, improve fish health, help restore and protect environments, extend the range of aquatic species, and improve the management and conservation of wild stocks. During the 1990s, research into biotechnologies increased, and scientists have identified and combined traits in fish and shellfish to increase productivity and improve quality. Scientists have increased investigation into genes that will increase production of natural growth factors in fish, as well as the natural defence compounds that marine organisms use to fight microbial infections. Faster growing salmon, vaccines made with recombinant DNA and bioremediation agents to improve aquatic environmental quality are now commonly available. However, while taking advantage of the benefits derived from biotechnology, we also need to understand the risks and act with caution.

Improving food quality and safety

In general, the safety and quality of internationally traded aquatic animal products has increased, mainly owing to stringent trading standards imposed by the European Union (EU) and the United States of America. National regulatory frameworks, residue testing and monitoring systems and other mechanisms to reduce contaminants and residues in aquatic products have been strengthened in many countries. However, there is still a significant need to improve compliance to the World Trade Organization’s Sanitary and Phytosanitary Agreement (WTO/SPS) and Codex Alimentarius requirements in many developing countries. As a consequence of the demand to demonstrate the safety and quality of aquatic products and the environmental integrity of such production systems, aquaculture certification and labelling has become a more common feature.

Promoting market development and trade

Aquatic products are increasingly traded globally, the volume having increased significantly over the past ten years. New markets have emerged, and new products have appeared in the market. With restrictions on fishing in certain seas, some aquaculture products found strong niche markets and became important commodities in aquatic food trade. Traceability and improved and value-added products entered into the market. Although it fluctuates, all in all, the price of cultured fish has declined over the past ten years, making fish an affordable food commodity to many.

Supporting strong regional and interregional cooperation

Over the past years, regional and interregional cooperation brought more benefits to aquaculture development. Many projects and programmes connecting countries and regions emerged, with several strong regional networks established. The Sub-Committee on Aquaculture of COFI was established in 2000, linking all FAO Members into an intergovernmental forum for aquaculture. This provided the necessary global focus to aquaculture. Whether or not governments and stakeholders literally took the Bangkok Declaration and Strategy as an important and agreed strategy to implement or as a quite comprehensive document covering almost all important aspects of sustainable aquaculture development, what is very clear is that reasonable progress was made in implementing the provisions of the strategy worldwide.

Conclusions

We believe that the Bangkok Declaration and Strategy will continue to guide the development and management of aquaculture beyond 2010 through to the first quarter of this century. However, there are elements of the Strategy that require further strengthening in order to enhance its effectiveness, to achieve development goals and to address persistent and emerging threats. By endorsing the Phuket Consensus, a draft document which you will find in your conference bag, we will re-affirm our commitment to the *Bangkok Declaration and Strategy for Aquaculture Development* and will recommend some new actions.

The future of aquaculture looks bright, but the challenges are also increasing. Considering the projected population growth over the next decades, it is estimated that an additional 35 million tonnes of aquatic food will be needed by 2030 just to maintain the current consumption level. Given the existing resources and technological advances, further expansion of aquaculture is only possible if the benefits are felt by everyone. The main challenge facing policy-makers and development agencies is to create an “enabling environment” for the aquaculture sector. Only in this way can aquaculture continue to grow while meeting peoples’ needs and preserving the natural environment. A mix of factors enables and constrains the growth of aquaculture as a sector: declining resource availability, tighter regulatory environment, global economic

development, increasing demand for fish and fishery products and conflicts with other resource users. Some of these constraints have led to the search for new opportunities. For example, there is a growing trend towards sea-farming where many countries are experimenting with off-shore and open-ocean aquaculture.

Amidst the global growth, aquaculture in Sub-Saharan Africa has been slow. Although the situation is changing and the rate of African aquaculture growth is picking up, it is still inadequate, considering that Africa holds the full range of resources needed for aquaculture growth. The overall contribution could be improved considerably, making Africa a high-priority region for aquaculture development. Development agencies and institutions should join hands in ensuring that aquaculture production in Sub-Saharan Africa becomes part of the continent's overall development course. Sustainable development of aquaculture requires government commitment to provide appropriate support to the sector. Commitment is seen in the form of clear policies, plans and strategies combined with adequate funding for their implementation. While a government commitment is necessary for responsible aquaculture development, it is not sufficient to ensure sustainability. The aquaculture sector needs to operate under sound macro-economic, institutional and legal frameworks. It needs private-sector investment.

In closing I would like to emphasize that, given the impressive growth rate the sector has recorded in the past three decades, aquaculture is gradually earning the recognition it deserves for its contribution to food security, poverty reduction, rural development and economic growth. All of us have a stake in this, so I hope that this Conference will bring new insights, crossing across and beyond boundaries, working together among and between groups and disciplines, bringing in science and treading through numerous and complex pathways, so that the fruits of its sustained and responsible development will benefit this generation and those that follow.

When we meet again, perhaps another ten years from now, I hope we shall be able to say with confidence that the conclusions of this Conference have yet again given greater impetus to the growth of aquaculture and that this Phuket Conference had marked the point when aquaculture embarked on the journey towards full maturity.

Thank You!





Part II – Invited guest lectures



Is feeding fish with fish a viable practice?

Invited Guest Lecture 1

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Abstract

The use of fish as feed for aquaculture is controversial. Some say that the practice should be reduced or stopped, arguing that it is not in the interest of consumers who otherwise would have eaten the fish used. Capture fisheries produces some 90–95 million tonnes of fish per year of which between 20 and 25 million tonnes are processed into fishmeal and oil. During the last two decades, a growing portion of the world's fishmeal and oil has been converted into fish and shrimp feed. Most of the 25–30 million tonnes are obtained by industrial fisheries in the North Atlantic and in the Pacific Ocean off South America. In Asia, by-catch, particularly from trawl fisheries for shrimp, is used as fish feed. It is believed that this may be on the order of 6 million tonnes/fish/year.

The farming of carnivorous fish and shrimp uses more fish as feed than is produced as finfish or shrimp. However, if the fish used as feed would not be consumed as food, then its use as feed might in the end lead to more food fish. Industrial fishing for forage species via manufacture of fishmeal and fish/shrimp feeds brings about a net contribution of food fish supplies without causing a systematic collapse of the exploited species. However, the practice of using bycatch as feed has apparently led to a decrease in the availability of fish as food for the very poor in some regions of Asia. Also, the ever-expanding demand for fish as feed is thought to endanger the long-term sustainability of targeted fish stocks.

Much of the “forage fish” used to produce fishmeal is edible. If this fish could be made available as low-cost food to the poor, no doubt their food security would improve. Aquaculture contributes about half of the world's seafood. Doubtlessly,

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the price of all fish would be substantially higher today if aquaculture did not exist. Most governments see unemployment as a problem; thus, jobs in feed fisheries, fishmeal/fish oil industries, fish/shrimp feed industries and aquaculture are positive contributions. In the absence of fishmeal/fish oil, most of these employment opportunities would likely not exist.

KEY WORDS: *Aquaculture, fish as feed, fishmeal, fish oil, forage fish, poverty alleviation, sustainability.*

Introduction

The issue and its context

The use of fish as feed for finfish and crustaceans is not uncontroversial. Many in the general public find it difficult to accept the practice of feeding fish to fish or shrimp instead of providing it as food to the poor and the starving. This feeling of unease is based on the idea that the practice reduces the quantity of food fish offered to the general public, as it is affirmed that more than one kilogram of fish – in the form of feed – is needed to grow one kilogram of carnivorous fish or shrimp in captivity. Also, the ever expanding demand for fish as feed is thought to endanger the long-term sustainability of fish stocks harvested to provide raw material for fishmeal and oil.

The author will analyse these arguments, focusing on feeds that are produced using fish landed by industrial fisheries and on those feeds that include fish obtained as bycatch. Consequences will be studied primarily in terms of (i) quantities of fish made available as food, and (ii) the employment that is created – or lost – in the process.

Fish used as feed instead of as food

Not all fish is used directly as human food. Yearly, capture fisheries produce some 90 to 95¹ million tonnes. Of this, somewhere between 20 and 25 million tonnes of fish² are regularly processed into fishmeal and oil. During the last two decades, a growing portion of the world's fishmeal and oil has been bought by the fish/shrimp feed industries and converted into fish and shrimp feed³. Most of the fish provided to the fishmeal plants is obtained by industrial fisheries in the North Atlantic and in the Pacific Ocean off the west coast of South America.

¹ Unless otherwise stated, all data on fish landings and aquaculture production are taken from databases published by the Food and Agriculture Organization of the United Nations (FAO).

² FAO reports on the use of fish in two categories: “for human consumption” and “for other purposes”. This second category in some contexts is broken down into: “reduction” and “miscellaneous purposes”. The figures quoted above refer to fish used for “reduction”, that is for processing into fishmeal and oil. The amounts of “bycatch” used as feed for fish would fall into the second category.

³ The International Fishmeal and Fish Oil Organization has estimated that in 2008 about 59 percent of the world fishmeal production was used by aquaculture. The corresponding figure for fish oil was 77 percent.

In East, Southeast and South Asia, bycatch, particularly from shrimp fisheries, is used as fish feed. Although there are no official statistics quantifying the magnitude of this practice in the countries concerned, it is believed to be on the order of 5 to 6 million tonnes/fish/year (Tacon, Hasan and Subasinghe, 2006). Some of this fish is converted into fishmeal, often of a crude variety, but most is fed raw, as part of farm-made fish feeds.

Finally, whole or chopped fish is used in growing quantities to feed captured juveniles of bluefin tuna. This practice, which is found in the Mediterranean, off Baja California in Mexico and along Australia's south coast, uses on the order of 0.3 to 0.4 million tonnes of fish annually as feed.

The argument

As mentioned above, there are two basic arguments against using fish as aquaculture feed: (i) it reduces the amount of fish available as food, particularly for the poor and (ii) the growing pressure for fish as feed will lead to overexploitation of forage species and threaten the future supply of fish.

The first argument – that the volume of fish as food falls as fish is used as feed – rests on the observation that frequently more fish is used as feed than is obtained as fish (or shrimp) on aquaculture farms; e.g. so many kilograms of fish (e.g. anchoveta) are used to produce a smaller quantity of salmon. The comparison implies that at the moment that the anchoveta (which is a small, delicate fish with a short shelf-life) or the menhaden is supplied to the fishmeal and oil plant, it could have been supplied to a local fish market and sold to waiting consumers. Ninety-nine times out of a 100 this is not the case. There is no market that could absorb, as food, the millions of tonnes of fish concerned. To put this another way: if there were no demand for fish as raw material for fishmeal and oil, the fishery for most forage species would stop.

Thus, it is important to understand that often even cheap fish (less than USD100 per tonne at dock-side) does not find its way into the diet of the poor. If we are concerned with supplying fish to the poor, we must of course be convinced that any additional fish we produce for that purpose actually finds its way to the food basket.

The first “basic” argument (above) is about how to maximize the quantity of fish that consumers will actually buy. It is not about maximizing the absolute amount of fish landed (in the long or short run) – it is about increasing the portion that is in fact accepted as human food. It will be seen that aquaculture, in fact, is an efficient method to transform unwanted fish into fish or shrimp acceptable as human food. It is a fact that until now the usual situation is that more fish is needed (in terms of live-weight equivalent) as feed than is obtained as food

through the culture of shrimp or carnivorous fish. This fact would seem to clinch the argument that aquaculture reduces the availability of fish⁴.

In its simplicity, the argument is appealing, but it ignores two fundamental facts: first, consumers must want to eat the fish (now used as fish feed) and second, they must have the money needed to pay the price the fisher and the processor/trader requires to cover the cost of production in the long run. The consumer must have an income, preferably in the form of cash, as barter is cumbersome. There is no point in having food fish available if it is not purchased, as it will then be of value to no one. So we should rephrase the issue; the author understands a more precise formulation of the first issue to be “does the use of forage fish as fish feed continuously and consistently reduce the amount of fish available and purchased for human consumption?”

How much food fish? viability measured by the quantities of food fish consistently made available (and purchased) through the use of fish as feed

Industrial fisheries: effects on food supplies

Industrial fisheries exploit small pelagic species, of which raw material for fishmeal and fish oil comes from some 14 species. Let us classify these species into three groups: (i) forage species not eaten as food as “industrial-grade forage fish”, (ii) species also marketed as food as “food-grade forage fish”, and (iii) fish with a regular market as food but which at times is also processed into fishmeal and oil as “prime food fish” (Table 1).

Industrial-grade forage fish

There are several forage species not in demand as food that are virtually exclusively used as raw material in fishmeal and oil production. Among these, the most significant are the menhaden (*Brevoortia* spp.), fished off the southeastern United States of America, and sandeels (Ammodytidae), fished off the Danish west coast. During the period 2003–2007, the average landings amounted to 0.65 million tonnes for menhaden⁵ (FAO, 2009a). Sandeel landings in Denmark amounted to about 0.6 million tonnes at the turn of the century, then fell drastically, but in 2009 had reached about 0.3 million tonnes⁶.

⁴ However, this is not a rule for each and every species. It is a rule that applies on the average. For some species and culture systems, it applies, for others, it does not. If 100 kg of anchoveta would produce 20 kg of fishmeal, this meal is used in a fish feed with an inclusion rate of 10 percent and the feed conversion ratio (FRC) is 1.6, then 100 kg of anchoveta would yield 125 kg of fish. The explanation is of course that only 10 percent of the feed is fish – the rest is also important. But in this discussion opportunity costs are not placed on ingredients other than those originating in fish. This is of course somewhat unrealistic.

⁵ Gulf menhaden (*Brevoortia patronus*) and Atlantic menhaden (*B. tyrannus*).

⁶ Danish Ministry of Fisheries, home page: www.Fvm.dk/English.

It seems to be beyond dispute that by converting these species to fishmeal and oil and then using part of that meal in fish feeds, the world ends up having more food fish than if this practice were not undertaken. The amount of industrial forage fish involved is on the order of 1.2 million tonnes per year; see Table 1). If 60 percent of the resulting meal would be used in fish feeds, the additional annual supply of food fish would be on the order of 0.7 million tonnes⁷. Equally, it is beyond doubt that if there were no fishmeal plants willing to use these species as raw material, the fisheries for them would cease.

TABLE 1

Volume of fish landed and estimates of quantities converted to fishmeal and oil, average for 2001–2006 classified by degree of acceptability as human food, for 14 countries with largest fishmeal production

	Country reporting landings	Landings (tonnes)	% of landings converted into fishmeal & oil ¹	Tonnes converted into fishmeal & oil
		Average 2001–2006 ²		
Industrial-grade forage fish				
Sandeels (<i>Ammodytes</i> spp.)	Denmark	387 500	100	
	Faeroe Islands	7 000	100	
	Sandeels	92 000	100	
Gulf menhaden (<i>Brevoortia patronus</i>)	USA	479 000	100	
Atlantic menhaden (<i>B. tyrannus</i>)	USA	212 000	100	
Norway pout (<i>Trisopterus esmarkii</i>)	Norway, Denmark, Faeroe Islands	52 000	100	
Total		1 229 500	100	1 229 500
Food-grade forage fish				
Anchoveta (<i>Engraulis ringens</i>)	Peru	7 200 000	98	7 056 000
	Chile	1 268 000	98	1 243 000
Japanese anchovy (<i>E. japonicus</i>)	China	1 142 000	67	765 000
	Japan	425 000	50	212 500
European anchovy (<i>E. encrasicolus</i>)	South Africa	228 000	50	114 000
	Morocco	18 500	50	9 000
Anchovies (Engraulidae)	Thailand	155 000	50	77 500
Sardinellas (<i>Sardinella</i> spp.)	Thailand	128 000	50	64 000
Capelin (<i>Mallotus villosus</i>)	Norway	229 000	50	115 000
	Iceland	665 000	75 ³	500 000
	Faeroe Islands	36 500	100	36 500
	Canada	28 000	0	0
Blue whiting (<i>Micromesistius poutassou</i>)	Norway	720 000	100	720 000
	Iceland	359 000	95 ³	341 000
	Denmark	65 000	100	65 000
	Faeroe Islands	254 500	100	254 500
European sprat (<i>Sprattus sprattus</i>)	Norway	5 000	100	5 000
	Denmark	257 500	100	257 500
Total		13 184 000	89.8	11 834 500

⁷ See Table 3 for the parameters.

TABLE 1 (Continued)

	Country reporting landings	Landings (tonnes)	% of landings converted into fishmeal & oil ¹	Tonnes converted into fishmeal & oil
Prime food fish				
Chilean jack mackerel (<i>Trachurus murphyi</i>)	Peru	274 000		
	Chile	1 475 000		
	China	121 000		
Chub mackerel (<i>Scomber japonicus</i>)	Peru	87 000		
	Chile	418 000		
	China	442 000		
	Japan	432 500		
Japanese jack mackerel (<i>T. japonicus</i>)	Mexico	24 000		
	China	109 000		
South American pilchard (<i>Sardinops sagax</i>)	Japan	211 000		
	China	182 000		
	Japan	68 500		
	South Africa	263 000		
Pacific herring (<i>Clupea pallasii pallasii</i>)	USA	85 000		
	China	46 000		
	USA	37 000		
	Japan	4 000		
Indian mackerel (<i>Rastrelliger kanagurta</i>)	Canada	24 000		
	Thailand	155 000		
	USA	96 000		
Atlantic herring (<i>C. harengus</i>)	USA	96 000		
	Iceland	238 000	50 ³	119 000
	Denmark	135 500		
	Canada	187 000		
	Mexico	471 000		
Cape horse mackerel (<i>T. capensis</i>)	South Africa	26 000		
European pilchard (<i>Sardina pilchardus</i>)	Morocco	639 000		
Total		6 250 500		

¹ Figures in italics are “guesstimates” by the author and should be verified.

² Source: Perón, Mittaine and Le Gallic (2010).

³ Source: www.fisheries.is/main-species/pelagic-fishes

Food-grade forage fish

The second category of fish used as raw material for fishmeal and oil production is the “food-grade forage fish”. These are species that people eat, albeit for which demand is small and often localized. Generally, the quantities that can be harvested yearly by industrial fishing vessels far outstrip the demand for these species as human food. The most well-known example is the fishery for the anchoveta (*Engraulis ringens*). In the Pacific Ocean, anchoveta is the principal “food-grade forage species”. During the period 2003–2007, the average landings of anchoveta were 8.3 million tonnes (landings in Peru and in Chile, Table 1).

Although it is a food-grade fish, only a very small amount is eaten. Peruvian consumers probably could eat somewhat more, but are not willing to do so, in spite of decade-long efforts by the public sector and the industry to develop alternative products and find new markets.

There is no realistic scenario under which the Peruvian population would be able to consume 7–8 million tonnes of anchovies in a year. The per capita consumption of anchoveta would need to reach about 0.75 kg/person/d. Peru has a well-established fish canning industry⁸. It is present on the world market, but has not, despite much effort, managed to create a significant international market for canned anchoveta.

Elsewhere, several species of anchovy (Engraulidae) have high-priced niche markets world-wide (salted, smoked or processed into paste, butter, cream, etc.), but in absolute terms the quantities handled in these niche markets are small.

In the North Atlantic, the three principal species in this category are European sprat (*Sprattus sprattus*), blue whiting (*Micromesistius poutassou*) and capelin (*Mallotus villosus*). Over the five year period 2003–2007, the average landings of sprat were about 0.6 million tonnes. In Sweden and Denmark, a few percent of landings are supplied as food, while in Finland, most of the landings are used as feed in mink farms (European Parliament, 2005). Blue whiting is processed into fishmeal or offered for human consumption, depending on where it is landed. In continental Europe (Netherlands, France, Germany, Spain and Portugal), the fishery is mainly for human consumption, while landings in the United Kingdom, Ireland and Denmark are traditionally destined for processing into fishmeal (EU Parliament, 2005). Canada, Norway, Iceland and the Faeroe Islands fish for capelin. During the period 2001–2006, their combined average landings were 0.93 million tonnes (Perón, Mittaine and Le Gallic, 2010). In both Iceland (FAO, 2009b) and Norway, the share used as food is slowly increasing.

In respect of “food grade forage fish”, it does not seem as if the fishmeal industry is withdrawing fish that food fish markets could have absorbed. The reverse seems to be the case: fishmeal plants make use of fish that the fresh fish market and the fish processing industries cannot absorb. This is definitely the case for the 8–10 million tonnes of fish that are processed yearly into fishmeal in Peru and Chile. It also seems likely to be the case for several of the “food-grade forage species” caught elsewhere.

The 14 largest producer countries for fishmeal and oil during the period 2001–2006 seem to have been using about 12 million tonnes (see Table 1) of “food grade forage species” to produce fishmeal and oil. Accepting that 60 percent of

⁸ In 2008, 73 canning factories processed 197 000 tonnes of fish (FAO Fishery Country Profile, Peru, in press).

the fishmeal is used by the aquaculture industry, this means that currently the industry provides at the very minimum about 7 million tonnes of aquaculture produce, which would not have been supplied in the absence of the world's fishmeal industries.

Prime food fish

World-wide, species like sardines, herring and mackerel are considered as high-quality food fish, and there are well-established food fish markets for these species. Nevertheless, smaller or larger quantities of these species and other prime food fish intermittently end up as raw material in fishmeal and oil manufacture.

The manner in which prime food fish is exploited differs from region to region and is essentially a consequence of the nature of the market for the product in the region where the fish is landed. In regions with low population densities but with ample fish resources (e.g. west coast of South America, southwest coast of Africa) much of the fish ends up as raw material for fishmeal. In other regions (e.g. Europe, North Africa, the United States of America) where relatively large populations can be reached from fish landing centers, the fisheries are organized as food fisheries, and one could expect that the “prime food fish” should not end up as fishmeal⁹.

There are two main reasons that it does: large fluctuations in landings and the extreme perishability of several of the species. The large fluctuations in landings mean that for economic reasons shore-based facilities are not constructed to a scale such that the largest of catches – which occur only for a short period each season – can be handled. So annually, there are periods when landings exceed the volumes that can be processed as food and, as they travel badly, the best alternative becomes processing them into fishmeal. This seems to happen regularly to landings of European pilchard (*Sardina pilchardus*) in Morocco¹⁰.

During the period 2001–2006, the 14 main fishmeal and oil producing countries landed an average of 6.25 million tonnes of sardines, mackerel and herring. There are no comprehensive and global statistics indicating what proportion of these landings are regularly used as food.

⁹ In fact, for this group of species, availability for industrial processing is likely to decline over time as demand for the species as food increases. An example is found in Norway “where 80 percent of herring catches were used for oil and meal some 20 to 25 years ago, while today the picture is reversed: 80–85 percent goes to human consumption and the remaining (bad quality) for oil and meal.” (Bjørn Hersoug, personal communication, August 2009). However, during the second half of the first decade of the current century, the international fishmeal price trebled. This has increased prices paid for forage fish and reduced the volume of cheap fish available as food.

¹⁰ Atmani, (2003) describes this situation for Morocco “When the raw material is at a low level, the canning plants work on a rotation basis as during the low season; when there is a glut of landings a considerable part of the catch goes to fishmeal.”

Why isn't more forage fish sold as food?

“Industrial-grade forage fish” has no viable markets as food. So fishing for them is viable only if the species is used as raw material for fishmeal and oil. “Food-grade forage fish” are generally considered low-quality fish, and consumers prefer other, more expensive species, when they can afford them. As these species are abundant, they provide a source of livelihood for fishermen, but then they rely on the fishmeal and oil industries to absorb most of the catches, even if prices at quay-side are low¹¹. In densely populated and prosperous regions, “prime food fish” are exploited for the food market; but sardines, mackerels and herring are cheap fish compared to other marine prime food fish. Nevertheless, most skippers and owners of fishing vessels have an interest in selling “prime food fish” catches to the food markets, as prices in these markets generally are superior to those offered by fishmeal manufacturers¹² (Hasan and Halwart, 2009). Naturally, to sell into these markets, the fish usually has to be in better shape than what is demanded by the fishmeal and oil industries, and that may mean higher costs for the skipper/vessel owner.

Other arguments against use of fish as feed

Leave the fish in the water

There is another argument advanced against the use of forage species as fish or shrimp feed. It says: “Let all these forage species remain in the water. They are prey for other fish which consumers want to eat and which will be caught”. It might be possible to catch a larger amount of the predators if industrial fishing ceased for key prey species, but as the conversion ratio in the wild is on the order of 10 kg of prey to 1 kg of food fish, the aquaculture alternative is much more productive. It provides at least about 6 kg¹³ of additional fish for every 10 kg turned into fishmeal and oil (allowing for a 40 percent “loss” of fishmeal as feed for livestock and other uses).

It is morally wrong to feed fish to fish and crustaceans

The last argument is ethical in nature. It affirms that it is not equitable that fish is fed to fish when people are starving. If so, then there is a moral obligation on those who catch and sell fish to provide it to those who need fish in order to have a nutritionally adequate diet.

It is often not clear whether this argument assumes that the poor shall receive the fish free of charge, at a subsidized price or pay the full costs. Providing large quantities of fish free of charge is expensive. If some 8 million tonnes of anchoveta were supplied yearly to the one billion hungry in the world, it would provide them with about 8 kg/person/year (live-weight equivalent). If the fish

¹¹ In Denmark, prices for forage fish fluctuated between Euro 80 and 130 per tonne during the period 1996–2002 (European Parliament, 2005).

¹² In Norway, capelin supplied as food pay better than capelin sold for reduction (www.nofima.no/marked/en/nyhet/2010/06/).

¹³ See Table 3 for the parameters.

were to be supplied in the form of canned products, the annual cost would be on the order of USD25 billion per year¹⁴. This does not look like a financially feasible alternative¹⁵, no matter how beneficial for the recipients. In addition, a subsidized product – canned or in another form – would, even if the quantities were much more modest, most likely be challenged under World Trade Organization (WTO) agreements; and this could happen even if the product did not enter international trade.

In summary, it seems clear that using fish landed by industrial fisheries in North America, Europe and on the west coast of South America as feed for food fish and crustaceans in the long run significantly expands the effective supply of fish for human consumption. The addition seems to be at least on the order of between 7 and 8 million tonnes of fish per year. If industrial fishing came to a halt world-wide, this would cause a closure of much of the fish feed and fishmeal and oil industries. It would also lead to an immediate annual loss of fish as food. In the long run, supplies of fish as food would increase, drawing upon the increase supplied from the fish now converted to fishmeal; however, this growth would be slow, as it would be dictated by population growth combined with rising living standards and would compensate for only a part of the fish lost.

If the global society wants to abruptly change the present pattern of using forage fish and ensure that “food-grade forage fish” is used as food upon capture instead of as feed, two actions would probably be necessary: (i) an agreement under the WTO that “food-grade” forage fish can be sold in subsidized form in specific countries; and (ii) a commitment that grants be provided in amounts required to subsidize fish processing companies dedicated to increasing the volumes of food produced from small pelagics. Such a decision would add to the supply of fish for human consumption, but the addition would be smaller than the amount of fish processed for human consumption, as a reduced supply of raw material for fishmeal and oil plants would result in a reduction in aquaculture production by an amount equal to between one quarter and one third of the fish processed as food.

Industrial fisheries: long-term effects on sustainability

It is soon 40 years ago that a dramatic and rapid collapse of the Peruvian anchovy fishery supplying local fishmeal and oil factories drew the attention of the world to the effects of unregulated fishing. Since then all major industrial fisheries for small pelagic species have come under management. In the United States of America, authorities manage the fisheries for menhaden. In the Northeast Atlantic, the North Sea and in the Pacific off the west coast of South

¹⁴ The “back-of-the-envelope” calculation: 10 kg of fish is equivalent to 3.3 kg in canned form. Each kg of canned product is retailed at the equivalent of USD1 per 100 g or USD10 per kg, so each individual receives canned fish worth USD26 per annum. For one billion poor, thus the total amount is USD26 billion.

¹⁵ The annual budget of the World Food Programme for 2008 was USD2.9 billion

America, industrial fisheries¹⁶ are all subject to an array of fishery management mechanisms (*inter alia*, total allowable catch (TAC), Area Catch Limits, minimum mesh size and satellite tracking) based on stock assessments carried out by the International Council for the Exploration of the Sea (ICES) (Europe), the Instituto del Mar del Perú (IMARPE) (Peru) and the Instituto de Fomento Pesquero (IFOP) (Chile).

These management measures, in and by themselves, will not undo what has been done in the past. Neither will their promulgation ensure sustainability of the stocks concerned. Many skippers participating in these fisheries are, like most capture fishermen, subject to perverse incentives. Therefore public resources must be deployed to enforce these regulations. However, the likelihood that stocks will collapse because of too much fishing effort has been drastically reduced during the past 40 years through the introduction of fisheries management. Also the fishmeal and oil industry needs a sustainable fishery. It is not served by a collapse of the fish stocks that it needs to harvest year after year. Thus, the industry can be counted on to be a moderating factor vis-à-vis the fleet sector.

Farm-made feeds using bycatch: effect on food supplies

When bycatch has no or very low value, fishermen usually discard it back into the sea. This will also happen to commercial species if on-board storage space is a constraint or if management regulations dictate that only a certain quantity of fish can be caught and smaller specimens are worth less per kilogram than larger ones.

Traditionally, retained bycatch has provided food for the poor in and around fishing centers, particularly in Africa and Asia. Bycatch was either cured (salted, dried, smoked) or consumed fresh. This is still the situation in most of sub-Saharan Africa, as culture of marine shrimp and marine fish has not yet reached significant volumes in most coastal countries.

In Asia, the situation today is different. As culture of marine shrimp and marine fish spread, so did the practice of preparing farm-made feeds, and trash fish became a common ingredient (New, Tacon and Csavas, 1994). Estimates from the mid-1990s have placed the amount of low-value fish used in aquaculture at 5 to 6 million tonnes per year (Tacon, Hasan and Subasinghe, 2006). It is not clear how much of this low-value fish is converted into fishmeal and how much is fed directly to fish and shrimp. However, it seems that while bycatch of small pelagics (and trimmings) may be a source of raw material for the modern fishmeal and oil industry in Europe and South America, this is rarely the case in Africa and Asia. This is not to say that some bycatch in South, Southeast and

¹⁶ For capelin, blue whiting, sandeel, sprat, herring, Norway pout, anchovy, jack mackerel and sardine (Fin Dossier, 2008).

East Asia (and then often not small pelagics) may not be reduced to fishmeal in artisanal fishmeal units. Such fishmeal, however, is not well suited as an ingredient in shrimp and fish feeds.

If stopping this practice would have the consequence that between 5 and 6 million tonnes of fish were added to the food market, then the practice causes a significant drain on food supplies. Also, it is not compensated by the aquaculture production that it will have generated¹⁷, particularly as the produce (marine shrimp, prime finfish) will be priced well beyond what the poor can afford in fishermen communities and adjacent rural areas and towns.

However, not all of this low-value fish is bycatch; some is the product of directed fisheries. Apparently, the most important directed fisheries for low-value fish exists or existed in Viet Nam¹⁸, yielding up to 0.6 million tonnes/year. In other fisheries, the crew may have retained bycatch that they would normally return to the sea, in order to sell it for feed use. The portion of the 5 to 6 million tonnes that has been made available because of this effect is not known. Although studies do not seem to be available, if the use of low-value fish or bycatch for aquaculture feed were to be stopped suddenly, it seems likely that in the long run the full 5 to 6 million tonnes would not be available as food. The amount that would become available would be somewhat lower, possibly between 4 and 5 million tonnes.

Juveniles of commercial food fish: a bycatch component

Juveniles of commercial species are frequently part of the bycatch. If the use of bycatch as a source of low-cost fish for aquaculture feed does not lead to any modification of the fishing undertaken before this practice was started, then the use of fish as feed cannot be labelled as a cause of decreased commercial landings of the target species. However, if the use of bycatch as fish feed causes an increase in the fishing effort and possibly an increased targeting of the “bycatch” (including the juveniles), then it would seem appropriate to consider the net loss of food fish caused by this practice as equivalent to a net loss of food fish in the concerned fisheries, a loss that is likely to be several times the volume of cultured shrimp and fish obtained from fish feeds composed of juveniles. However, the author has not found quantitative data on this feature of bycatch, and it is not further considered here.

In summary, most likely, the practice of using low-value fish as fish and shrimp feed has led to a decrease in the availability of fish as food for the very poor but

¹⁷ On the order of 3.0 million tonnes if the feed was used exclusively for shrimp and marine fish and the efficiency is similar to that obtained from industrial feeds incorporating the same amount of raw fish but in the form of fishmeal (between 2.8 and 3.4 million tonnes using parameters from Table 3). However, some dried fish/artisanal fishmeal is also used in traditional and semi-intensive culture of catfish and carps (Hasan, 2007).

¹⁸ Source: Presentation given by M.S. Dao, V.T. Dang and D.B. Huynh Nguyen. Some information on low value trash fish in Vietnam, given at the Regional Workshop on Low Value and Trash Fish in the Asia Pacific Region. Hanoi, June. 2005.

possibly also for others in some regions of South, Southeast and East Asia. The quantities are significant; 4.5 million tonnes over a year could deprive 1 billion individuals of 4.5 kg fish/person/year (live weight equivalent)¹⁹. From the point of view of these consumers, this reduction is not compensated by the 3 million tonnes or so of aquaculture produce, as the species produced are generally priced far above what poor, local consumers can afford.

Farm-made feeds using bycatch: long-term effects on resource sustainability

Bycatch (particularly from trawling) frequently includes immature specimens of commercial species. This is a fisheries management problem that is difficult to address, but partial remedies exist, and the problem can be contained and reduced in severity. If it is not, and the use of bycatch in farm-made feeds causes an increase in fishing effort²⁰ – in order to sell bycatch to those who make farm-made feeds – then aquaculture can be held responsible for jeopardizing the sustainability of the concerned food fisheries. The severity of this naturally varies from case to case and is a function of the initial status of the stocks and the intensity of the bycatch problem. Again, the question becomes empirical: what is the extent of this problem? The author has not found any reply to this question in the literature.

Whole fish as feed for bluefin tuna: effects on food supplies

As farmed Atlantic bluefin tuna (*Thunnus thynnus*) is fed on fish, the conversion factor is low; reported FCRs varying from 1:7 to 1:20 (Tacon, Hasan and Subasinghe, 2006). In this discussion, the author will use an FCR of 1:15, meaning that, on average, 15 kg of raw fish would be needed to obtain 1 kg weight gain for the captive bluefin tuna.

No agreed statistics seem to exist as to the global production; however, just after the turn of the century, there seemed to be a consensus that production had reached about 20 000 tonnes/year (Halwart, Soto and Arthur, 2007) in the Mediterranean, which probably accounted at the time for about two-thirds of the global production. Global production has grown, but by how much? In order not to underestimate the amount, let us assume that production is 50 000 tonnes globally.

Tuna is fattened mostly on sardines, but also on horse mackerel, squid and other food-quality forage species. So, the “loss” of food fish is undisputable. To the author, it seems difficult to argue otherwise. The reason is that capture fisheries stagnate, while consumption of fish increases steadily by a few percent

¹⁹ About the same as one quarter of the global average consumption for about 15 percent of the world's population.

²⁰ In the form of longer fishing hours or gear modifications intended to result in more bycatch, which then becomes target catch.

a year, thanks to aquaculture. No doubt in the long run, food-grade forage fish now fed to bluefin tuna could find markets as human food.

How much fish is used as feed? Although the size of tuna, both when stocked and harvested, varies considerably, except for a small Japanese production, other practices all seem to aim (at the most) to double the weight of the stocked species. That means that the weight gain for the industry as a whole might have been on the order of 25 000 tonnes and the amount of feed fish used, some 375 000 tonnes. By most measures, this is a significant amount of fish, if directed to the food fish market instead of used for tuna fattening.

Whole fish as feed for bluefin tuna: effects on resource sustainability

The demand for forage fish as feed for bluefin tuna in pens will have two effects on fisheries for these species. The immediate consequence could be that fish is directed to feed instead of to food use. However, the extent of such a reaction depends in turn on both institutional factors and on the state of the concerned stocks. The second consequence is an increased overall fishing effort on the concerned stocks, or at least this will develop an incentive to increase the fishing effort. It is this incentive that can create problems where the stock is already fully fished and management is absent or ineffective. Given the volumes used to date and the geographical spread of the activity, the risk of a stock collapse seems low.

Who can afford the fish?: viability measured by affordability

So far in this analysis, we have established: (i) that use of fish for producing fishmeal and oil on the whole increases the supply of food fish, and the order of magnitude is about 8 million tonnes/year; (ii) that the use of bycatch as aquaculture feed reduces the supply of fish as food by some 1 to 2 million tonnes annually; and, (iii) that fattening of bluefin tuna reduces the supply by some 0.4 million tonnes/year. Taken together, total food fish supply is increased. However, in the market fish has a price²¹, so of paramount interest is “at what price is this additional fish made available?”, or phrased differently, “who will eat the ‘additional’ fish generated through the use of fish as feed for crustaceans and finfish?”

Most of the high-quality fattened bluefin tuna will be eaten in Japan in high-priced restaurants. However, the other products that rely heavily on fish protein (e.g. salmon, shrimp, seabass, seabream) are also not low-cost species. Although these species are not the high-cost items they used to be, it can be

²¹ Even the World Food Programme's (WFP) non-emergency food aid is usually delivered as part of pay packet – that is, not free of charge.

safely argued that as a rule the fish and shrimp produced by the aquaculture industry will not become part of the diet of the poor, and particularly not of the poor in developing countries.

On the other hand, aquaculture today contributes about half of all the seafood eaten in the world. Doubtlessly, the price of all fish would be substantially higher today if aquaculture did not exist. This will have also benefited the very poor. It is agreed naturally, that the merit of this development does not lie solely with the use of fish as feed, as not all aquaculture uses feed or fish in one form or another, as feed²².

Viability measured by employment (income earned)

So far the discussion has concerned the consumers. We have looked at the total supply of food fish and quickly, at who, among consumers, benefits or loses as the fish becomes cheaper or more expensive. However, there is another group of individuals involved: those whose livelihood is affected by activities linked to providing fish as feed. They may have found a way to secure their livelihood in aquaculture that depends on fish as feed, or they may have lost one, trading bycatch as food. How they are affected is at least as important as the implications for any other group in society. For many individual consumers, the effects are marginal²³. They eat a little bit more or a little bit less fish. However, for the fisher, the fish factory worker or the fish trader, the consequences may be much more important; they may gain or lose a source of income and their livelihood.

In this context, it is fundamental to recall the pivotal role of income in the eradication of poverty. That income is important may sound like a truism – and maybe it is. But, what it means in this particular context is that for the poor – rural or urban – a steady source of income is more important in the long run than access to cheap fish or other cheap food (World Bank, 2007) made available in food help programmes, often of limited duration.

Income earned from feeding fish to fish: industrial fishing

A large number of individuals of different professions have a role to play in the chain of activities that connects the fishery for forage species, via fish feed manufacture and the aquaculture farm, to the consumer. Unfortunately, the extent and nature of the employment that this chain of activities provides is not known with any precision. Few countries systematically collect data on employment for all the various components of the chain²⁴. So there is no way of knowing with certainty what employment exists or can be created in this value

²² With the exception of feed for salmonids, most aquaculture feeds contain more ingredients of plant origin than ingredients originating in marine fauna.

²³ Exceptions made for those among the very destitute who have bycatch as part of their survival diet.

²⁴ This situation exists in most countries, developed as well as developing.

chain. It seems that the best that can be done is to try to make reasonable estimates²⁵ based on a few examples.

First part of the value chain

The main components of the “industrial fisheries” value chain are: (i) fishing for forage fish, (ii) converting the fish into fishmeal and oil, and (iii) producing industrial fish and shrimp feeds incorporating fishmeal/fish oil. These activities have in common that they are relatively capital intensive, or looked at from the perspective of labour, they employ relatively few workers. The first two take place at or close to the fishing grounds. The third is not necessarily located at the same place as the fishmeal/oil manufacture.

Industrial fishing for forage fish is productive, when measured in terms of tonnes landed per fisherman and year. In Peru the productivity is close to 100 tonnes per fisherman-year (Wijkström, 2009), while in the European Union (EU), it is on the order of 700 tonnes. The Peruvian fishmeal industry employs people at a rate of about 0.77 man-year per 1 000 tonnes of raw material (Wijkström, 2009). In the EU, total employment is on the order of 250 man-years, giving an employment rate of only 0.14 man-year per thousand tonnes of raw material²⁶.

The author has no information on the employment in the fish and shrimp feed manufacturing industries. However, although this is likely to be a mechanized activity, given that it takes place closer to the point of use of the food (particularly in Asia), the labour intensity is likely to be considerably higher than for the fishmeal and oil industry. A rate of one man-year per 1 000 tonnes of fish (or 220 tonnes of fishmeal) would give an additional employment of about 8 000 full time equivalents (FTEs) per year.

Thus, the additional employment created in the first part of the value chain by the additional 13 million tonnes of “additional” forage fish procured by the industrial fisheries will be on the order of 100 000 in terms of FTEs.

In summary, the first part of the value chain is not labour intensive. If it disappears, for whatever reason, the economies concerned will notice it, but it will not imply that a major industrial restructuring will follow.

Second part of the value chain

The second part of the value chain starts with the aquaculture enterprise and ends with the retailing of the fish and shrimp produced. The economic

²⁵ One can build an estimate starting with examples of employment for different activities that are part of the chain. One can also infer a number by considering the value, at retail level, of the final product (aquaculture produce, forage fish sold to consumers, bycatch sold to consumers) and by knowing the cost structure of the various component activities, deduct the maximum number of direct employment that can be paid as a result.

²⁶ See Fin Dossier (2008).

TABLE 2

Additional employment in fishing, fishmeal manufacture and fish/shrimp feed manufacture generated by the processing of 13 million tonnes of forage fish into fishmeal and oil, and of 8 million tonnes of fishmeal into fish/shrimp feeds

	Man-years (FTE) ¹ per 1 000 tonnes of forage fish	Quantities produced (million tonnes)	Total additional employment
Fishing	6.25 ²	13	81 000
Fishmeal manufacture	0.65 ³	13	8 400
Fish/shrimp feed manufacture	1.0 ⁴	8	8 000
Total			97 400

¹ FTE = full time equivalent.

² A weighted average of the productivity in Peru (100 tonnes/fisherman-year) and the EU (700 tonnes/fisherman-year).

³ A weighted average of the productivity in Peru (0.77 man-years to handle 1 000 tonnes of fish) and the EU (0.14).

⁴ Author's assumption.

characteristics of the culture system used by fish and shrimp farmers differ according to the location – and therefore the surrounding economy – of the activity. Salmon culture in Norway is capital intensive compared to shrimp farming in Southeast Asia, which is labour intensive. Direct employment in salmon culture is low per tonne produced. In the EU, the productivity is on the order of 100 tonnes per person (FTE) and year (SINTEF, 2005); in Norway, it is somewhat higher and in Chile lower²⁷.

However, indirect employment is considerable. In the EU, the productivity of the processing industries and associated indirect employment was on the order of 12 tonnes per person-year (FTE) (SINTEF 2005).

Information about employment in shrimp culture is spotty. The author has used (Wijkström, 2009) a figure of 1.33 man-years per tonne of shrimp produced. A large part of those employed are manual labourers. To this should be added employment in processing (freezing, canning), storage, transport and sales of shrimp products. These are likely to be considerable. The author has not found any published data on these employment effects and placed them, conservatively, he believes, at equal to those on the farm: 1.33 man-years per tonne of shrimp produced.

Earlier in this article, the author concluded that the industrial fisheries create an additional supply of food fish of some 7 million tonnes annually. The other side of this coin is that a number of individuals earn an income from this additional production.

²⁷ The differences in labour productivity are considerable in the aquaculture sector. For example, fish farmers in Norway have an average production of 172 tonnes per person, while in Chile it is at about 72 tonnes, in China 6 tonnes and in India only 2 tonnes (FAO, 2010).

As can be seen in Tables 3 and 4, most of this employment is generated in labour-intensive aquaculture (shrimp culture) and relatively little in the fishing, fishmeal manufacture and fish and shrimp processing industries. Of the 3.7 million additional employment (FTE), some two thirds occur in shrimp culture. In this context, it is worth noting that while most of the employment takes place in developing, or emerging, economies, most of the fish and shrimp produced are consumed in Organisation for Economic Co-operation and Development (OECD) economies.

TABLE 3

Additional employment in aquaculture (and downstream) enterprises using fish feeds that incorporate fishmeal obtained from processing 8 million tonnes of forage fish into fishmeal and oil¹

	Share of global fishmeal in 2008 (%) ^a	Fishmeal inclusion rate in feed in 2007 (%) ^b	Total amount of feed produced (million tonnes)	Feed conversion ratio (feed produced/cultured output) (2007) ^b	Total cultured output (million tonnes)	Labour productivity (tonnes/man-year)	Total additional annual employment (8 million tonnes of forage fish ²)
Salmon & trout	29	24	2.67	1.2	2.22	100 ^c 12 ^e	17 760 148 000
Shrimp	28	18	344	1.7	202	1.3 ^d 1.3 ^e	1 240 000 1 240 000
Marine fish	21	30	153	1.9	81	5 10 ^e	129 600 65 000
Other	22	5	960	1.7	565	10 10 ^e	452 000 452 000
Total	100		1 724		1 070		3 754 360

¹ Source: ^aAndrew Jackson, personal communication, July 2009; ^bTacon and Metian (2008); ^cSINTEF (2005); ^dWijkström (2009); ^eThe productivity existing in associated processing and indirect employment (see text above).

² In 2008, just above 60 percent of world fishmeal production was used in aquaculture (FIN Dossier, 2008). So of the output produced from the 13.3 million tonnes “additional” forage fish made available to the fishmeal industry annually, some 60 percent would have been supplied to fish and shrimp aquaculture some years ago.

TABLE 4

The employment effect per year of using fish as an ingredient in farm-made feeds: an exploratory calculation

	Effect	Volume of fish handled/year (million tonnes)	Labour productivity (tonnes/man-year)	Total employment (million man-years)
Directed fisheries	Increase	1.0	10	0.1
Preparation of aquaculture feeds	Increase	6.0	15	0.4
Curing and retailing low-value fish	Decrease	5.0	7	(0.7)
Aquaculture	Increase	3.0	3	1.0
Total				0.8

Employment from feeding fish to fish: use of bycatch

The employment situation in the chain of activities that start with allocating bycatch to use as fish feed and ends with retail sale (or its equivalent) of the aquaculture produce is less documented than it is for the group of activities supplying fish as feed via preparation of fishmeal and oil.

First part of the value chain

The first part of the value chain consists of the fishing, up to and including off-loading of the bycatch at quay-side (or its transshipment at sea). As has been stated above, employment on board, in terms of number of crew and their activities, does not change greatly because of the use of bycatch as feed. In most situations, the fishing patterns are not altered because of a new use for the bycatch, nor are activities on deck. The bycatch should be separated from the target catch under most circumstances. The same reasoning applies to those engaged in moving the bycatch on quay-side.

This means that once it has reached shore, the end use of the bycatch does not much affect either the number of individuals employed or what they do in the first part of the value chain. However, the fisheries dedicated to the catch of low-value fish to be used as fish feed have a positive employment effect. As these are high-volume fisheries, productivity, measured in tonnes landed per fisherman-year, will be higher than it is for the average Asian fisherman, about 2.5 tonnes/man-year (FAO, 2009b). Using a productivity of 10 tonnes/man-year would mean that 100 000 fishermen would be employed to land 1 million tonnes.

Second part of the value chain

When low-value fish is sold as food, the value chain in its second part consists of transport of fish direct to retail markets and subsequent retailing; or, if direct marketing is deemed unfeasible, the fish is transported to fish-curing sites. In the latter case, labour is involved in the curing – a process lasting days or weeks – and subsequently in transporting (storing) and retailing the final cured product.

The bycatch bought as raw material for feed follows two value chains. It can be taken to fishmeal plants and processed. However, many such fishmeal plants in South and Southeast Asia are rudimentary, and the product frequently does not reach the standards demanded by shrimp and fish farmers. Much of the product is used as feed for chickens and ruminants.

Most of the bycatch or low-value species bought is but one of the ingredients in farm-made fish and shrimp feeds. This value chain includes the preparation of the feed, the subsequent aquaculture activity and ends with the processing and marketing of the aquaculture produce. The transport of bycatch, the preparation of farm-made feeds and the feeding itself are labour-intensive tasks. However,

the author has not found any documented facts that permit a comparison of the employment generated by making farm-made feed with the use of labour as low-value fish is brought to markets to be sold as food, in fresh or cured form. His belief is that fish retailing – where mechanization is difficult – is considerably more labour intensive in terms of man-years of employment per unit of bycatch handled than the feed processing alternative – where mechanization is a distinct possibility.

The retailing of bycatch as food is of course not carried out in circumstances similar to those in which cultured fish or high-value finfish are retailed. Retailing of bycatch as food will be considerably more labour intensive. One reason is that the retailing of the aquaculture produce may occur thousands of miles from the place in which the fish or shrimp grew to market size, and where the low-value fish is retailed.

The culture of fish and shrimp constitutes the last part of the value chain. This activity generates employment, and the number of workers involved is considerable, given the large volume of low-value fish that is used. Does it generate more or less work on-farm than does the same amount of forage fish converted into fishmeal and industrially manufactured feeds? Given that the fish, when it arrives at the farm is four to five times heavier when it arrives there in the form of raw fish than as fishmeal, more work on-farm is needed with raw fish. For this same reason, larger aquaculture units soon find it necessary to mechanize the handling of feeds²⁸. Also, by necessity manual labourers on farms are not strictly specialized, but perform more than one duty, particularly if they work full time

In summary, the use of low-value fish as feed probably has a positive overall effect on employment. The relatively large loss of employment in processing and retailing of low-value fish as food is compensated by increased employment in three distinct areas: (i) fisheries directed at low-value fish; (ii) the preparation of farm-made feeds (including raw fish), and (iii) increased aquaculture production. An exploratory calculation indicates that the additional employment, some years back, may have been approximately 0.8 million man-years (see Table 4).

Some short-term consequences of the continued use of fish as feed

There is little doubt that fish will continue to be in demand. A growing population and increased popularity of fish will mean that global demand will grow faster than the global population. Most likely, aquaculture will continue to deliver

²⁸ It has been reported that even traditional catfish farms in Viet Nam have introduced machinery to facilitate the handling of trash fish (FAO, 2009b).

the additional quantities²⁹; thus, there will also be a growing demand for fish feeds, and for such feeds to incorporate animal proteins or future equivalent ingredients.

On the one hand, it will be increasingly difficult for aquaculture to capture an even larger share of the total fishmeal supplies, and the price of fishmeal will continue to be high and may increase further. Fishmeal manufacturers will thus be able to afford prices much above the USD100 per tonne that seemed the standard during much of the end of the last century and the beginning of this century. When the fishmeal manufacturer can afford to pay USD300 per tonne of forage fish, then the industry will have the potential to purchase fish that today, under normal market conditions, would have been supplied to the food fish market. Such a trend is likely to cause much controversy.

In parallel with a growing demand for fish and for fishmeal, feed manufacturers and aquaculturists are putting considerable efforts into a search for alternatives to fishmeal and oil in fish and shrimp diets (Naylor *et al.*, 2009). As the price of fishmeal and oil increases, the economic space for replacing them will also grow, and during the coming decades, it seems more than likely that the aquaculture industry will make less use of fish as feed, per kg of seafood produced, than it does at present.

The use of bycatch as fish feed is likely to decrease during the next ten years. There are several reasons. One is economic – to transport and process the large volumes of fish involved is labour intensive, and as economies grow and salaries rise in Southeast and East Asia, the practice will rapidly become too costly. Simultaneously, there are health risks associated with the practice which will cause fish and shrimp farmers to prefer pelleted feeds. Lastly, managers of commercial fisheries are likely to have some success in their efforts to reduce bycatch generally.

If the future will be as just described, will the use of fish as feed continue to be viable? Let us look at the same “measuring rods” that we used to assess the situation today.

- *Sustainability of resources* – If fisheries management is going to become more effective, which seems likely, then there would be less grounds to expect that in the near future industrial fisheries will be a threat to the survival of feed fisheries or of fish stocks that are part of their ecosystem. Similarly, the bycatch problem – in terms of harmful quantities of juveniles – is being addressed; if anything, it will be better handled. This may lead to less bycatch but better sustainability for commercial food fish fisheries.

²⁹ During the decade 1995–2005, the per capita supply of fish in the world grew at an average annual rate of 1.0 percent (1.7 percent in the preceding decade), while aquaculture production during the same decade grew at an annual rate of 7.1 percent (11.8 percent in the preceding decade) (FAO, 2009b).

- *Volume of food fish supplied* – This is probably the big question mark. If the work on replacing fishmeal does not yield results, and therefore the price of fishmeal continues to rise, there is a considerable possibility that the search for raw material for fishmeal plants will lead to falling quantities of cheap forage fish on food fish markets. Measured in pure volume, such a development would doubtless lead to less food fish on the market overall. The same reasoning applies to tuna fattening based on raw fish. If we focus only on the volumes of food fish made available, tuna fattening can only be classified as a wasteful exercise.
- *Price level of food fish supplied* – As volumes of production grow for a species, its market price tends to come down. This is a well-established fact. However, at the global level, there may be a shift upwards in demand for fish. This may come about, on the one hand, because the general public realize the nutritional benefits of fish vis-à-vis other animal protein foods, and on the other hand, the public may perceive that the global warming effects of cultured fish are smaller, on a kilogram by kilogram basis, than are those of production of meat by ruminants.
- *Additional income earned and employment from using fish as fish feed* – Economic growth, with the accompanying technological growth, could lead to a slow fall in employment, without necessarily a parallel fall in total income.

Conclusion

Given that overall: (i) the amount of fish available as food is larger when fish is used as feed than without this practice; (ii) that the price of fish globally is reduced because of aquaculture; (iii) that employment is larger with the practice than without it; (iv) that reduction fisheries can be, and increasingly are managed effectively, the practice of using fish as feed is viable, that is, use of fish as feed is capable of surviving as a practice during coming decades.

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The potential of nutrient-rich small fish species in aquaculture to improve human nutrition and health

Invited Guest Lecture 2

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Abstract

Small fish are a common food and an integral part of the everyday carbohydrate-rich diets of many population groups in poor countries. These populations also suffer from undernutrition, including micronutrient deficiencies – the hidden hunger. Small fish species, as well as the little oil, vegetables and spices with which they are cooked enhance diet diversity. Small fish are a rich source of animal protein, essential fatty acids, vitamins and minerals. Studies in rural Bangladesh and Cambodia showed that small fish made up 50–80 percent of total fish intake in the peak fish production season. Although consumed in small quantities, the frequency of small fish intake was high. As many small fish species are eaten whole; with head, viscera and bones, they are particularly rich in bioavailable calcium, and some are also rich in vitamin A, iron and zinc. A traditional daily meal of rice and sour soup, made with the iron-rich fish, “trey changwa plieng” (Mekong flying barb, *Esomus longimanus*), with the head intact can meet 45 percent of the daily iron requirement of a Cambodian woman. Small fish are a preferred food, supplying multiple essential nutrients and with positive perceptions for nutrition, health and well-being. Thus, in

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areas with fisheries resources and habitual fish intake, there is good scope to include micronutrient-rich small fish in agricultural policy and programmes, thereby increasing intakes which can lead to improved nutrition and health. The results of many studies and field trials conducted in Bangladesh with carps and small fish species have shown that the presence of native fish in pond polyculture and the stocking of the vitamin A-rich small fish, “mola” (mola carplet, *Amblypharyngodon mola*), did not decrease the total production of carps; however, the nutritional quality of the total fish production improved greatly. In addition, mola breeds in the pond, and partial, frequent harvesting of small quantities is practiced, favouring home consumption. A production of only 10 kg/pond/year of mola in the estimated four million small, seasonal ponds in Bangladesh can meet the annual recommended intake of six million children. Successful aquaculture trials with polyculture of small and large fish species have also been conducted in rice fields and wetlands. Thus, aquaculture has a large, untapped potential to combat hidden hunger. To make full use of this potential, further data on nutrient bioavailability, intra-household seasonal consumption, nutrient analyses, cleaning, processing and cooking methods of small fish species are needed. Advocacy, awareness and nutrition education on the role small fish can play in increasing diet diversity and micronutrient intakes must be strengthened. Measures to develop and implement sustainable, low-cost technologies for the management, conservation, production, preservation, availability and accessibility of small fish must be undertaken. Also, an analysis of the cost-effectiveness of micronutrient-rich small fish species in combating micronutrient deficiencies using the Disability-Adjusted Life Years (DALYs) framework should be carried out.

KEY WORDS: *Aquaculture, Fish species consumption, Human nutrition, Micronutrients in fish species, Nutrient-rich small fish species.*

Introduction

Drawing mainly on data from Bangladesh and Cambodia, this paper focuses on the importance of nutrient-rich small fish in aquaculture in supplying essential nutrients, in particular vitamin A, calcium, iron and zinc to vulnerable population groups. In developing countries with fish resources, fish and fisheries play an important role in the livelihoods, income and diets of many, especially the rural poor, who also suffer from undernutrition, including micronutrient – vitamin and mineral – deficiencies, termed “hidden hunger”. It is estimated that 190 million children worldwide are affected by vitamin A deficiency; two billion people have an insufficient iodine intake; 1.6 billion (almost 25 percent) of the world’s population are anaemic, half of this due to iron deficiency; and many suffer from zinc deficiency.¹

¹ World Health Organization. Vitamin and mineral nutrition information system (VMIS). Micronutrient database (accessed May 2011; available at: www.who.int/vmnis/database/en).

These deficiencies increase the risk of morbidity and mortality from diarrhoea and measles, cause xerophthalmia and anaemia, and negatively affect growth and cognitive development in children, reproductive performance and work productivity. It is estimated that maternal and child undernutrition accounts for 11 percent of total Global Disability-Adjusted Life Years (DALYs), with dire consequences for national and global development (Black *et al.*, 2008). Aquaculture technologies which include nutrient-rich small fish in polyculture of carps and freshwater prawn have shown great potential in alleviating hidden hunger.

Fish species consumption in bangladesh and cambodia

Official estimates of fish production and consumption tend to exclude the fish caught, consumed and traded in rural areas, and therefore the benefits that are derived from fish are not well documented and are grossly underestimated. In addition, the data from surveys in which food consumption has been reported do not include intra-household consumption or fish consumption at the species level. Consumption surveys in selected areas of rural Bangladesh showed that the amount of fish consumed varies with location and household economic status, and is highly seasonal. Fish was the third most commonly consumed food, after rice and vegetables. In poor households with little land, the mean fish intake ranged from 13 to 83 g of raw, whole fish/person/d (Thompson *et al.*, 2002).

In a study conducted in 84 households in Kishoreganj, Bangladesh in three rounds (July 1997, October 1997 and February 1998), the highest total fish intake was recorded in October, with small indigenous fish species (SIS, growing to a maximum length of 25 cm or less) making up a much greater proportion (84 percent) of the total fish intake than large fish. Five species: “puti” (barbs, *Puntius* spp.), silver carp (*Hypophthalmichthys molitrix*), “taki” (spotted snakehead, *Channa punctata*), “baim”/“chikra” (lesser spiny eel, *Macrognathus aculeatus*; zig-zag eel, *Mastacembelus armatus*; barred spiny eel, *Macrognathus pancalus*), and “mola” (mola perchlet, *Amblypharyngodon mola*), in descending order of percentage of total fish intake, made up 57 percent of the total fish intake. The SIS, “puti”, covering 10 species, with three (*P. sophore*, *P. chola* and *P. ticto*) being the most commonly consumed, both fresh and fermented, made up 26 percent of total fish intake, calculated as raw, edible parts. The frequency of fish, especially SIS, consumption was high; nearly all households consumed SIS on at least one out of five consecutive days (Roos, Islam and Thilsted, 2003a). Thus, SIS is an integral part of the everyday, rice-dominated diet, and with the little oil, spices and vegetables with which they are cooked enhance diet diversity.

In a small study conducted in 66 poor, rural households in Svag Rieng Province, Cambodia in 1997–1998, an average intake of 70 g raw, edible parts of fish/

person/d, as well as 9 g/person/d of other aquatic animals (OAA, for example, frog, snail and snake) were recorded (Toft, 2001). In fish communities around Tonle Sap Lake, Cambodia, it was estimated that the average fish intake was 128 g raw, cleaned parts/person/d in 1998 (Ahmed *et al.*, 1998).

These studies showed that small fish made up 50–80 percent of all fish eaten in the peak fish production season in rural Bangladesh and Cambodia. There are increasing concerns that fish intakes in these countries, as well as in other developing countries are decreasing due to factors such as population growth, increased urbanization, rising incomes and high consumer preferences for fish, especially in Asia. In Cambodia, there are concerns that the construction of dams on the Mekong River will decrease the amount of fish caught. In Bangladesh, changes in the overall agricultural system, especially rice production, as well as in the use of land and water cause continued decline in the areas of inland water and inundation, reducing the habitats for fish and cutting off migratory routes from breeding grounds. This has contributed to decreased fish intake, in particular SIS intake among the rural poor. Concomitantly, the intake of silver carp from pond aquaculture has risen and the proportion of SIS in the total fish intake has decreased (Thompson *et al.*, 2002).

In the above-mentioned study in Kishoreganj, Bangladesh, the rural market was the most important source of fish, 57–69 percent of the total fish intake being derived from this source, while fish caught by household members accounted for 16–37 percent of total fish intake. Market prices of fish varied considerably; in the lean fish production season (July), the prices were nearly double those in the peak season (October). “Puti” and mixed SIS were cheapest, and most SIS were cheaper than large fish, with the exception of silver carp, which was as cheap as many SIS (Roos *et al.*, 2007d).

In recent years, “mola” has become common in markets and supermarkets in the capital, Dhaka. The demand for “mola” may have increased due to the awareness of it being beneficial for nutrition and health, in spite of its high price, much higher than many carp species. Also, the amounts of Nile tilapia (*Oreochromis niloticus*) and “pangas” (striped catfish, *Pangasianodon hypophthalmus*) available in urban markets are increasing due to large-scale aquaculture production.

Nutrient contents of some common fish species

Table 1 shows the vitamin A, calcium, iron and zinc contents of some common fish species in Bangladesh and Cambodia (Thilsted, Roos and Hassan, 1997; Roos *et al.*, 2007c). Some common SIS have high contents of preformed vitamin A, mainly as retinol (vitamin A-1) and 3,4-dehydroretinol isomers (vitamin A-2). The proportions of vitamin A-1 and A-2 vary considerably between species. In “chanda” (Himalayan glassy perchlet, *Parambassis baculis*), vitamin A-2

TABLE 1
Vitamin A, calcium, iron, and zinc contents in selected common fish species in Bangladesh and Cambodia¹

Common name ²	Scientific name	Contents per 100 g raw, cleaned parts				
		Vitamin A (RAE) ³	Calcium (g)	Calcium ⁴ (g)	Iron (mg)	Zinc (mg)
mean ± SD (n) ⁵						
Bangladesh						
SIS ⁶						
Baim/Chikra (Lesser spiny eel)	<i>Macrogathius aculeatus</i>	90 ± 15 (3)	0.4 ± 0.1 (5)	0.2 ± 0.0 (5)	2.4 ± 0.4 (5)	1.2 ± 0.2 (5)
(Barred spiny eel)	<i>M. pancalus</i>	90 (1)	— ⁷	—	—	—
(Zig-zag eel)	<i>Mastacembelus armatus</i>	30 (1)	—	—	—	—
Chanda (Indian glassy fish)	<i>Parambassis ranga</i>	1 679 ± 1 000 (3)	1.0 ± 0.3 (5)	0.9 ± 0.3 (5)	1.8 ± 0.7 (5)	2.3 ± 0.6 (5)
(Himalayan glassy perchlet)	<i>Pseudambassis baculis</i>	340 ± 105 (3)	—	—	—	—
(Elongate glass-perchlet)	<i>Chanda nama</i>	170 (1)	—	—	—	—
(Flying barb)	<i>Esomus danricus</i>	890 ± 380 (3)	0.9 ± 0.4 (3)	0.8 ± 0.3 (3)	12.0 ± 9.1 (3)	4.0 ± 1.0 (3)
Dhela	<i>Osteobrama cotio cotio</i>	937 (1)	1.3	—	—	—
Kachki (Ganges river sprat)	<i>Corica soborna</i>	90 ± 20 (7)	0.5 ± 0.0 (2)	0.4 ± 0.0 (2)	2.8 ± 1.2 (2)	3.1 ± 0.5 (2)
Mola (Mola carplet)	<i>Amblypharyngodon mola</i>	2 680 ± 390 (7)	0.9 ± 0.1 (3)	0.8 ± 0.0 (3)	5.7 ± 3.7 (3)	3.2 ± 0.5 (3)
Puti (Pool barb)	<i>Puntius sophore</i>	60 ± 20 (3)	1.2 ± 0.2 (4)	0.8 ± 0.1 (4)	3.0 ± 0.9 (4)	3.1 ± 0.5 (4)
(Swamp barb)	<i>P. chola</i>	70 (1)	—	—	—	—
(Ticto barb)	<i>P. ticto</i>	20 (1)	—	—	—	—
Taki (Spotted snakehead)	<i>Channa punctata</i>	140 ± 45 (3)	0.8 ± 0.2 (3)	0.3 ± 0.1 (3)	1.8 ± 0.4 (3)	1.5 ± 0.2 (3)
Commonly cultured large fish species: carps						
Mrigal (Mrigal carp)	<i>Cirrhinus cirrhosus</i>	< 30 (1)	1.0 ± 0.1 (3)	0.0 ± 0.0 (3)	2.5 ± 1.3 (3)	—
Silver carp	<i>Hypophthalmichthys molitrix</i>	< 30 (3)	0.9 ± 0.4 (3)	0.0 ± 0.0 (3)	4.4 ± 1.8 (3)	—
Cambodia						
SIS						
Changwe mool (Yellowtail rasbora)	<i>Rasbora tornieri</i>	374 ± 111 (3)	0.7 ± 0.0 (3)	—	0.7 ± 0.1 (3)	2.7 ± 0.2 (3)
Chunteang phluk	<i>Parachela siamensis</i>	480 ± 35 (3)	0.6 ± 0.1 (3)	—	1.2 ± 0.3 (3)	2.2 ± 0.1 (3)
Kangtrang preng (Duskyfin glassy perchlet)	<i>Parambassis wolffi</i>	260 (1) ⁸	1.1 ± 0.1 (3)	—	1.4 ± 0.5 (3)	1.6 ± 0.3 (3)
Trey changwa pleng (Meikong flying barb)	<i>Esomus longimanus</i>	415 (1)	0.8 ± 0.2 (3)	—	11.3 ± 3.4 (5)	4.9 ± 0.5 (3)
Commonly cultured large fish species: snakeheads						
Indonesian snakehead	<i>Channa micropeltes</i>	—	1.1 ± 0.1 (3)	—	1.2 ± 0.1 (3)	1.4 ± 0.1 (3)
Great snakehead	<i>C. marulius</i>	200 (1) ⁸	1.4 ± 0.2 (3)	—	1.5 ± 0.9 (3)	1.5 ± 0.1 (3)

¹ Source: Thilsted, Roos and Hassan (1997), Roos et al. (2007c).

² Fish species are listed in alphabetical order of local common name in each subgroup. Where available, FishBase recognized common names (www.fishbase.org/) are given in parentheses.

³ RAE = retinol activity equivalent.

⁴ In raw, edible parts, after correcting for calcium in the plate waste (mainly bones).

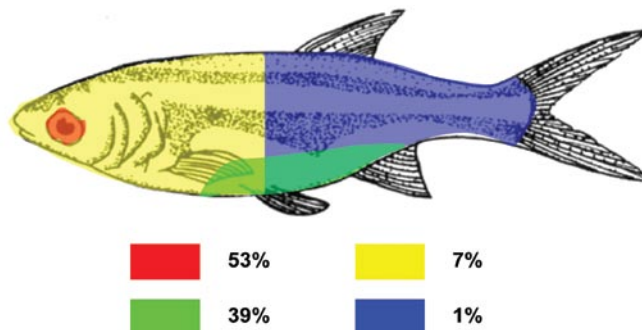
⁵ n = number of samples. For SIS, a sample consisted of 10–300 fish and for large fish, 1–2 fish.

⁶ SIS = small indigenous fish species.

⁷ — = not measured.

⁸ Measured in raw, whole fish.

FIGURE 1
Distribution of vitamin A in “mola”. Vitamin A content: 2,680 RAE¹/100 g
raw, edible parts. Length of whole “mola”: 6–8 cm;
weight of raw, whole “mola”: 5–9 g.²



¹ RAE: retinol activity equivalent.

² Source: Roos *et al.* (2002).

accounts for 90 percent of the total vitamin A content, expressed as retinol activity equivalent (RAE), and 20 percent in “darkina” (flying barb, *Esomus danricus*). Analysis of the different parts of mola showed that the eyes contain the highest proportion of the total vitamin A, followed by the viscera (Figure 1) (Roos *et al.*, 2002, 2007a; Roos, Islam and Thilsted 2003a, b). As most SIS are eaten whole with bones, they are a very rich source of calcium. The two *Esomus* species, “darkina” from Bangladesh and “trey changwa plieng” (Mekong flying barb, *E. longimanus*) from Cambodia have significantly higher iron content than the other analyzed species. Iron in fish is in the form of haem iron, a high molecular subpool of complex-bound non-haem iron, and inorganic iron, the proportions varying with species. These two fish species also have a high zinc content (Roos *et al.*, 2007b).

The nutritional contribution of fish species

Fish, and in particular small fish species are a rich animal-source food of multiple essential nutrients. It is well recognized that all fish species are a rich source of animal protein, and some have a high fat content and beneficial polyunsaturated fatty acids. However, there has been little focus on the contribution of fish as a rich source of vitamins and minerals. In the above-mentioned study in Kishoreganj, Bangladesh, SIS contributed 40 percent and 31 percent of the total recommended intakes of vitamin A and calcium, respectively, at the household level, in the peak fish production season (Roos *et al.*, 2006).

In order to quantify the nutritional contribution of a fish species, it is important that the cleaning practices be documented, the discarded parts recorded and weighed before cooking or processing, and with respect to raw fish, nutrient analyses be carried out on samples of raw, cleaned parts, and the plate waste recorded and

analyzed. Processing of fish is a common practice; in Bangladesh, some SIS and small prawn are dried, and some SIS are also fermented in the peak production season. In Cambodia, a proportion of fish is consumed as fish paste, fish sauce, dried salted fish, fermented and smoked fish (Chamnan *et al.*, 2009).

Sun-drying of “mola” resulted in nearly all vitamin A being destroyed (Roos, Islam and Thilsted, 2003b). As the majority of vitamin A in “mola” is found in the eyes, to ensure a high vitamin A contribution, it is important that the head is not removed during cleaning, but cooked, and the head and eyes are consumed, which is a common practice.

In Kandal Province, Cambodia, it was recorded that the majority (80 percent) of households cooked “trey changwa plieng” with the head intact. Calcium, iron and zinc contents in raw, cleaned samples with head were considerable higher (58, 25 and 53 percent, respectively) than in samples in which the head was discarded during cleaning (Thorseng and Gondolf, 2005). With respect to calcium contribution, the size of the fish and the plate waste are important factors. Large fish (e.g. carps) do not contribute to calcium, as the bones are plate waste (Table 1). SIS are generally eaten whole, without plate waste, making them an extremely rich source of calcium.

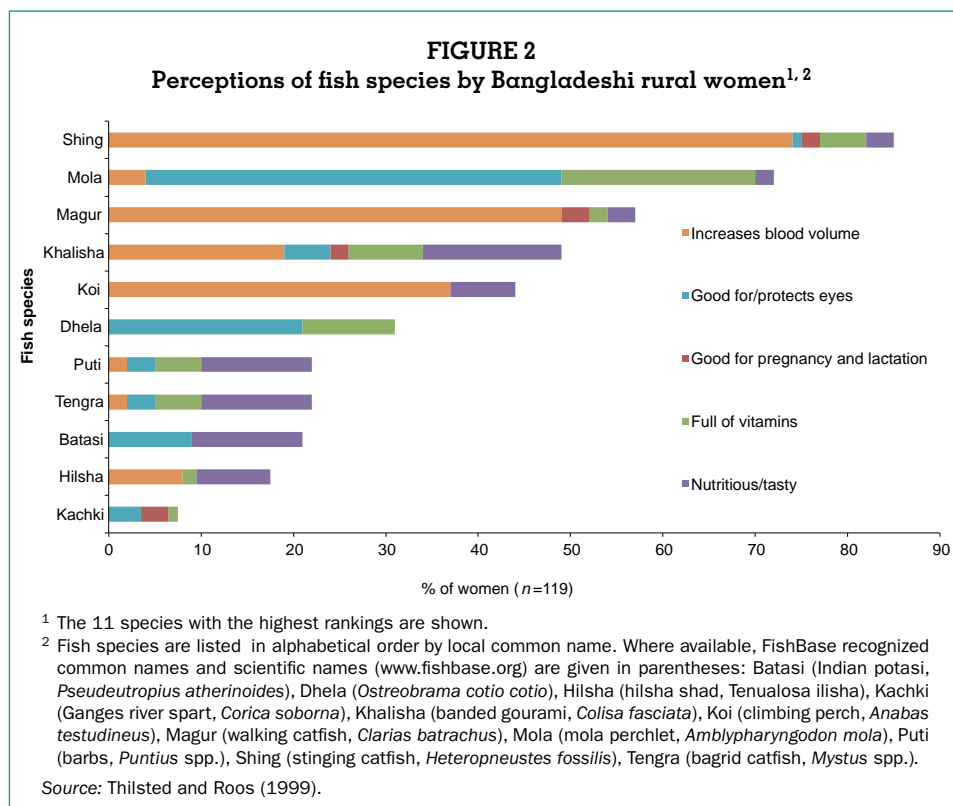
The bioefficacy of preformed vitamin A and bioavailability of minerals in fish species are major factors for determining their nutritional contribution. A biological activity of 40 percent in relation to *all-trans* retinol is used to calculate RAE from vitamin A-2 in fish samples, based on the growth response of vitamin A-2 in rats (Shantz and Brinkman, 1950). Calcium in “mola” was shown to have the same high bioavailability as that from milk in both rats and humans (Hansen *et al.*, 1998; Larsen *et al.*, 2000). The bioavailability of the iron fractions found in fish is estimated to be 25 percent for both haem iron and the complex-bound non-haem iron, and 10 percent for inorganic iron. The cooking method can affect bioavailability: a Cambodian fish dish of boiled “trey changwa plieng” contained more haem iron than one that was fried (Roos *et al.*, 2007b). Zinc bioavailability from animal-source foods, including fish is considered to be high.

Boiled rice and sour soup is one of the most common, traditional meals consumed by poor, rural households in Cambodia. An average meal consumed by women consisted of 367 g boiled rice/woman/meal and 257 g sour soup containing 49 g fish/woman/meal. If the sour soup is prepared with “trey changwa plieng”, this traditional meal can meet 45 percent of the daily median iron requirements of a Cambodian woman. An intake of 100 g sour soup containing 25 g “trey changwa plieng” in a child’s meal would contribute 42 percent of the daily median iron requirement (0.45 mg iron/child/d) (Roos *et al.*, 2007b). Moreover, besides providing easily absorbable iron, fish has been shown to have an enhancing effect on non-haem iron and zinc absorption from the meal in humans (Aung-Thun-Batu, Thein-Thun and Thane-Toe, 1976).

Perceptions of fish species for nutrition, health and well-being

Figure 2 shows the 11 fish species which received the highest ratings in a study among rural Bangladeshi women, in 1991/92 with respect to their perceptions of the benefits of eating fish species for nutrition, health and well-being. “Mola” and “dhela” (*Ostreobrama cotio cotio*), with high vitamin A content were reported as being full of vitamins and good for the eyes (Thilsted and Roos, 1999). In a study in two fishing villages in Bangladesh, one floodplain and the other coastal, the same fish species were noted to have similar positive perceptions among local communities (Deb and Haque, 2011).

In the above-mentioned household survey in Kishoreganj in 1997/98, all household members ($n=481$, mothers reporting for children) were asked to name the fish species most preferred for consumption. “Rui” (roho labeo, *Labeo rohita*), a large indigenous carp was the most preferred species (reported by 24 percent of the respondents), followed by “mola” (13 percent) and “hilsha” (hilsha shad, *Tenualosa ilisha*) (11 percent). A SIS (with the exception of “puti”) was the most preferred species by 30 percent of the respondents, whereas “puti” and silver carp, the species with the highest intakes were preferred by less than 10 percent of the respondents (Roos, 2001). In a later study of 36 women and men



in three Bangladeshi villages, it was reported that although women were aware of the value of “mola” and “dhela” as a rich source of vitamin A, and being good for the eyes, especially for pregnant and lactating women; it was difficult to promote increased intakes in these vulnerable groups. The major constraints were low availability and accessibility of these SIS, as well as little importance given to the nutritional needs of women by men and mothers-in-law, key decision-makers in the family (Jeppesen, 2006).

Small fish species are a preferred animal-source food

SIS enjoy the status of being a preferred, everyday food, well-liked by all household members and with a high frequency of consumption. This, coupled with the positive perceptions of some small fish species as being good for nutrition and health, as well as reports that a dish made with small fish is more equitably shared among all household members (in contrast to one made with large fish) can be capitalized on to promote the consumption of micronutrient-rich fish species, especially in vulnerable population groups such as young children, pregnant and lactating women, the sick and elderly. Thus, micronutrient-rich small fish species hold an extremely favourable position for being included in the design and implementation of agricultural policy decisions and programmes to increase the intakes of animal-source foods in women and children.

Data from Bangladesh validate this approach. In the Nutrition Surveillance Project implemented by Helen Keller International in 2000, the frequency of consumption, in seven days preceding an interview, of four nutrient-rich foods (i.e. egg, fish, green leafy vegetables and lentils) was collected bi-monthly for over 51 000 rural children aged 12–59 months. Fish was the most frequently eaten food, vegetables and lentils were eaten on fewer than two days, and more than 60 percent of children had not eaten egg. Also, other household members rarely ate egg, even though more than 90 percent of households reported having poultry (HKI, 2002). A similar food frequency consumption pattern was recorded in mothers of children under five years of age, in rural Bangladesh in 2005. Fish was the second most frequently consumed food, after rice, followed by milk, lentils, green leafy vegetables, egg, red/orange/yellow vegetables and fruits, chicken and meat, in descending order of frequency of consumption (J. Waid, personal communication, February 2011).

In a very successful small-scale poultry production intervention, egg and poultry production was reported in a sample of intervention and non-intervention households. Expectedly, the production of chicken and egg was significantly higher in the intervention compared to the non-intervention households. Consumption data from one woman and one girl child under five years of age from each household showed that the intakes of egg and chicken were similar in all households; however, the intake of small fish was significantly higher in the intervention households compared to the non-intervention households. The women ranked small fish as the second most preferred food to buy with

increased household income. Fruits ranked first, leafy vegetables, third and two animal-source foods, milk and beef, fourth and fifth, respectively (Nielsen, Roos and Thilsted, 2003). These data show that in Bangladesh and perhaps other developing countries with fish as a common food, there is great scope to increase the consumption of this frequently consumed animal-source food, rich in multiple nutrients, including micronutrients, with high bioavailability, provided it is readily accessible.

Aquaculture from a nutritional perspective

In response to declining fish availability, the Government of Bangladesh, together with development partners embarked on projects to initiate aquaculture, with the aim of increasing fish production for sale, and thereby fish consumption. In the last 25 years, pond aquaculture, based on well-known production techniques of carp polyculture has flourished. The Mymensingh Aquaculture Extension Project (MAEP), with support from Danish International Development Assistance (Danida) was very successful, reaching 40 000 households, from 1989 to 1999. Large fish belonging to the carp species: silver carp – the dominant species, common carp (*Cyprinus carpio*), and the indigenous carps, “rui” and “mrigal” (mrigal carp, *Cirrhinus cirrhosus*) were produced in small homestead ponds. Before stocking of the carps into the ponds, eradication of self-recruiting species, the majority being SIS was practiced by repeated netting, dewatering and the use of a piscicide (rotenone), based on the rationale that there is competition between stocked and native fish. The amount of fish (measured as raw, whole fish) in the culture ponds rose to 1.0–3.7 tonnes/ha/year, compared to 0.5 tonnes/ha/year in ponds with traditional management practices (Roos *et al.*, 2007d).

Recognizing the above-described importance of SIS in the diets of rural Bangladeshis and the potential for supplying the limiting essential nutrients vitamin A, calcium, iron and zinc, a number of production trials with polyculture of carps and SIS have been conducted in small, seasonal and perennial ponds. In the first trials, carps were stocked without the eradication of SIS; in later studies, without eradication of SIS, carps were stocked with “mola”, as well as the giant river prawn (*Macrobrachium rosenbergii*) (Kohinoor *et al.*, 1998, 2001; Kohinoor, 2000; Roos, 2001; Wahab, Alim and Milstein, 2003; Roos, Islam and Thilsted., 2004; Kadir *et al.*, 2006; Milstein, Kadir and Wahab, 2008; Milstein *et al.*, 2009). No significant difference in total fish production was seen between ponds stocked with “mola” and those without “mola”. However, the nutritional quality of the total fish production improved considerably. “Mola” reproduced in the pond several times in the production season, and in order to avoid overpopulation, bi-weekly partial harvesting of “mola” was practiced. In one study, the use of the harvested “mola” was recorded; 47 percent was consumed in the household and the remainder was sold (Roos, Islam and Thilsted, 2003a).

This production technology of carps and “mola” in pond polyculture in Bangladesh has gained wide acceptance by the government and development partners working with rural populations. A breakthrough was made in 2004 when the Ministry of Fisheries and Livestock issued a directive to project directors in the fisheries extension services to implement carp/”mola” pond polyculture throughout rural Bangladesh. Also, non-governmental organizations (NGOs) working with poor, rural households in Bangladesh are implementing this technology. Furthermore, it has been successfully introduced in the Sundarbans, West Bengal, India², as well as in Terai, Nepal, with initial assistance from the Faculty of Fisheries, Bangladesh Agricultural University. In addition, on the dykes of ponds, seasonal, micronutrient-rich vegetables are being grown with the use of the nutrient-rich water and soil from the ponds. It is estimated that a small production of 10 kg/pond/year of the vitamin A-rich SIS, “mola”, in the four million small, seasonal ponds in Bangladesh can meet the recommended vitamin A intake of over 6 million children. As vitamin A is stored in the body, a high seasonal intake can be utilized to build up reserves to meet constant tissue needs. Aquaculture technologies combining production of large fish with nutrient-rich small fish are highly applicable in other developing countries in Africa and Asia with inland water resources and habitual small fish consumption.

In order that micronutrient-rich small fish production can become an integral part of aquaculture, priority must be given to conservation and management of common fisheries resources, including inland waterbodies such as beels (floodplain depressions and lakes) and fish migration routes. Work carried out on the reestablishment of fish migratory routes to floodplains resulted in restoration of fish habitats, a five-fold increase in total fish production and a doubling of the proportion of fish (mainly SIS) caught that was consumed by the landless and small farmers after restoration (CNRS, 1996).

Aquaculture is also being practiced in seasonal floodplains. Stocking of carp fingerlings and management, including enforcement of fishing regulatory measures in a large beel (40 ha) in northwest Bangladesh resulted in a total fish production of over 25 tonnes in six months, of which 45 percent were non-stocked fish, mainly SIS (Rahman *et al.*, 2008). Aquaculture in rice fields is also being done. In studies on the different combinations of fish species, both large fish and SIS, in rice-fish culture, higher yields of rice grain and straw were reported in rice fields with fish compared to those without fish; and the SIS, “dhela” was reported to be well-suited for culture (Dewan *et al.*, 2003). Trials have also been carried out with rice, giant river prawn and “mola” culture in rotation as well as concurrently (Wahab *et al.*, 2008, Kunda *et al.*, 2008, 2009).

² Source: Oral presentation given by M. Kunda, B. Mahakur, S. Sengupta, M.A. Wahab, S.H. Thilsted, and N. Roos. *Introducing the nutrient dense, small indigenous fish species, mola (Amblypharyngodon mola) in pond aquaculture with carps and prawn in the Sundarbans region, India.* 8th Asian Fisheries Forum, 20–23 November 2007, Kochi, India.

Depending on geographical location and season, these culture practices can increase productivity as well as the nutritional quality of the combined rice and fish production.

The above studies show that aquaculture has been successfully linked to the promotion of improved human nutrition and health in Bangladesh. Years of work in interdisciplinary research, participatory field trials and studies, laboratory analyses, documentation and publication of research results, information sharing between professionals in multiple sectors, in particular fisheries and nutrition and health, dissemination, capacity building, awareness, advocacy and policy-making have led to this success.

Firstly, the recognition that data collection at the fish species level of fish produced and caught, both non-stocked and stocked, and consumed, at the intra-household level was crucial for attempts to exploit the potential of aquaculture to improve nutrition and health, especially of the rural poor. A lot of interest was generated with documenting unequivocally that calcium from the bones of SIS was as bioavailable as that from milk, commonly regarded as the best source of calcium. Eliminating the use of rotenone to eradicate SIS was easy to implement as soon as the farmers were convinced that carp production is not reduced by leaving the SIS in the pond and stocking “mola”. Rotenone accounted for 10 percent of the total production costs, and the farmers are aware that the pond is not a closed system and that SIS also enter the pond, for example, with duckweed used for feeding. Establishing that “mola” breeds in the pond and frequent, partial harvesting of small amounts is necessary to control the stock was instrumental in increasing “mola” consumption – as this harvesting technique favours home consumption. On the other hand, the majority of carps are generally harvested all at once and sold immediately to a wholesaler at the end of the production season, five months or more after stocking. This harvesting pattern does not favour frequent home consumption.

In addition to the direct contribution of aquaculture in supplying essential vitamins and minerals, small-scale aquaculture which involves women is shown to have positive effects through increased household income, as well as the many factors related to women’s empowerment, including decision-making; access to economic, social and political resources; knowledge, training, education and mobility. These positive effects have the potential to benefit nutrition and health.

However, as nutrition is also determined by factors other than food and nutrients, care and health, for which women are generally responsible, it is important that the work load of women in aquaculture is taken into account. Participation of women in small-scale aquaculture in Bangladesh has shown to increase their work load, especially with feeding of fish, feed preparation and harvesting

(Shirajee, Salehin and Ahmed, 2010). At the same time, the participation of women, especially in small-scale aquaculture opens a natural entry to reaching women in their homes, with behaviour change communication and adoption of, for example, improved infant and young child feeding practices, including care, hygiene and sanitation.

Conclusions

This paper describes the missed opportunity which aquaculture can embrace for nutrient-rich small fish to play a substantial role in improving nutrition and health. This important benefit of aquaculture has been greatly overlooked. Small fish is a source of multiple essential nutrients, including vitamins and minerals which are not found in the staple food and are in inadequate amounts in the diets of the rural poor. However, SIS should not only be viewed as supplying essential nutrients, but first and foremost, as an irreplaceable animal-source food; an integral part of the everyday diet of rural populations. In cementing the role of SIS, firm steps must be taken to stop the use of the terms, “low value”, “trash fish” and “weed fish” for SIS, as well as to qualify the term “high value” (used for large fish), which refers specifically to “high market value”, in terms of price and not nutritional value. Aquaculture also offers scope for the development and implementation of nutrition-sensitive value chain activities, for example, in processing and marketing.

To make better use of the potential of aquaculture to improve nutrition and health, the WorldFish Center, Bangladesh has recently initiated a project “Linking fisheries and nutrition: promoting innovative fish production technologies in ponds and wetlands with nutrient-rich small fish species in Bangladesh”, with financial support from the International Fund for Agricultural Research (IFAD). The major components include production of carps and “mola” in household ponds and wetlands, integrated with the promotion of SIS consumption by women, in particular pregnant and lactating women, and young children from six months of age, as well as behaviour change communication and adoption of improved practices of infant and young child feeding. This project builds on concepts of linking agriculture and nutrition and health, incorporated in, for example, the Consultative Group for International Agricultural Research (CGIAR) Research Programmes, in particular 1.3 “Harnessing the development potential of the aquaculture agriculture systems for the poor and vulnerable”, 3.7 “More meat, milk and fish by and for the poor” and 4 “Agriculture for improved nutrition and health”, as well as the United States Agency for International Development (USAID)-funded initiative “Feed the future”. Aquaculture can also contribute to the Scaling up Nutrition (SUN) movement, in providing micronutrient-rich SIS which can be included in complementary foods for young children. In the project, WinFood, in rural Cambodia, a weaning food made of rice and two small fish, “trey changwa plieng” and “trey sloeuk russey” (*Paralaubuca typus*), with a high fat content (12 g fat/100 g raw, edible parts) is being fed to children, from

six months of age for nine months. Indicators of nutritional status are being measured.³

The recent hikes in global food prices place a great responsibility on aquaculture to ensure that SIS are available and affordable to the poor. Poor households must struggle harder to meet their need for staple foods, in an effort to ward off hunger. As a consequence, less money is available for spending on nutrient-rich foods, such as animal-source foods, vegetables and fruits, leading to decreased micronutrient intakes and high prevalence of hidden hunger.

In order that activities and investments in aquaculture can be focused and targeted to improving nutrition and health, research work in specific areas must be carried out. Further data on the bioefficacy and bioavailability of nutrients from fish, as well as on intra-household seasonal consumption at the species level, nutrient analyses, and the cleaning, processing and cooking methods of small fish are needed. Advocacy, awareness and nutrition education on the role small fish can play in increasing diet diversity and micronutrient intakes must be strengthened at all levels. Measures to develop and implement sustainable, low-cost, innovative technologies for greater management, conservation, production, preservation, availability and accessibility of SIS must be undertaken. In addition, an analysis of the cost-effectiveness of micronutrient-rich small fish species in combating micronutrient deficiencies should be carried out using the DALYs framework.

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³ Source: Poster presentation by N. Roos, M. Nurhasan, M., Bun Thang, J. Skau, F. Wieringa, Kuong Khov, H. Friis, K.F. Michaelsen and C. Chamnan,. *WinFood Cambodia: improving child nutrition through improved utilization of local food*. Biodiversity and sustainable diets: united against hunger. Symposium hosted by Bioversity International and FAO, 3–5 November 2010, Rome, Italy.

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Climate change impacts: challenges for aquaculture

Invited Guest Lecture 3

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Abstract

In spite of all the debates and controversies, a global consensus has been reached that climate change is a reality and that it will impact, in diverse manifestations that may include increased global temperature, sea level rise, more frequent occurrence of extreme weather events, change in weather patterns, etc., on food production systems, global biodiversity and overall human well being. Aquaculture is no exception. The sector is characterized by the fact that the organisms cultured, the most diverse of all farming systems and in the number of taxa farmed, are all poikilotherms. It occurs in fresh, brackish and marine waters, and in all climatic regimes from temperate to tropical. Consequently, there are bound to be many direct impacts on aquatic farming systems brought about by climate change. The situation is further exacerbated by the fact that certain aquaculture systems are dependent, to varying degrees, on products such as fishmeal and fish oil, which are derived from wild-caught resources that are subjected to reduction processes. All of the above factors will impact on aquaculture in the decades to come and accordingly, the aquatic farming systems will begin to encounter new challenges to maintain sustainability and continue to contribute to the human food basket.

The challenges will vary significantly between climatic regimes. In the tropics, the main challenges will be to those farming activities that occur in deltaic regions, which also happen to be hubs of aquaculture activity, such as in the Mekong and Red River deltas in Viet Nam and the Ganges-Brahmaputra Delta in Bangladesh. Aquaculture in tropical deltaic areas will be mostly impacted by sea level rise, and hence increased saline water intrusion and reduced

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water flows, among others. Elsewhere in the tropics, inland cage culture and other aquaculture activities could be impacted by extreme weather conditions, increased upwelling of deoxygenated waters in reservoirs, etc., requiring greater vigilance and monitoring, and even perhaps readiness to move operations to more conducive areas in a waterbody.

Indirect impacts of climate change on tropical aquaculture could be manifold but are perhaps largely unknown. The reproductive cycles of a great majority of tropical species are dependent on monsoonal rain patterns, which are predicted to change. Consequently, irrespective of whether cultured species are artificially propagated or not, changes in reproductive cycles will impact on seed production and thereby the whole grow-out cycle and *modus operandi* of farm activities. Equally, such impacts will be felt on the culture of those species that are based on natural spat collection, such as that of many cultured molluscs.

In the temperate region, global warming could raise temperatures to the upper tolerance limits of some cultured species, thereby making such culture systems vulnerable to high temperatures. New or hitherto non-pathogenic organisms may become virulent with increases in water temperature, confronting the sector with new, hitherto unmanifested and/or little known diseases.

One of the most important indirect effects of climate change will be driven by impacts on production of those fish species that are used for reduction, and which in turn form the basis for aquaculture feeds, particularly for carnivorous species. These indirect effects are likely to have a major impact on some key aquaculture practices in all climatic regimes. Limitations of supplies of fishmeal and fish oil and resulting exorbitant price hikes of these commodities will lead to more innovative and pragmatic solutions on ingredient substitution for aquatic feeds, which perhaps will be a positive result arising from a dire need to sustain a major sector.

Aquaculture has to be proactive and start addressing the need for adaptive and mitigative measures. Such measures will entail both technological and socio-economic approaches. The latter will be more applicable to small-scale farmers, who happen to be the great bulk of producers in developing countries, which in turn constitute the “backbone” of global aquaculture. The sociological approaches will entail the challenge of addressing the potential climate change impacts on small farming communities in the most vulnerable areas, such as in deltaic regions, weighing the most feasible adaptive options and bringing about the policy changes required to implement these adaptive measures economically and effectively.

Global food habits have changed over the years. We are currently in an era where food safety and quality, backed up by ecolabelling, are paramount; it was not so 20 years ago. In the foreseeable future, we will move into an era where

consumer consciousness will demand that farmed foods of every form will have to include in their labeled products the green house gas (GHG) emissions per unit of produce. Clearly, aquaculture offers an opportunity to meet these aspirations. Considering that about 70 percent of all finfish and almost 100 percent of all molluscs and seaweeds are minimally GHG emitting, it is possible to drive aquaculture as the most GHG-friendly food source. The sector could conform to such demands and continue to meet the need for an increasing global food fish supply. However, to achieve this, a paradigm shift in our seafood consumption preferences will be needed.

KEY WORDS: *Aquaculture, Climate change, Global warming, Deltaic regions, Paradigm changes in food habits.*

Introduction

Perhaps in modern history it will be difficult to find a more global science-based evaluation and associated documentation than that on climate change, its causative factors and potential impacts, and plausible mitigating and adaptive measures to combat such changes. In spite of the intensive science-based findings and scrutiny (IPCC, 2007), it still has its critics and non-believers (e.g. Lomborg, 2001; Hulme, 2009; Washington and Cook, 2011). However, it is correct to say that the overwhelming scientific consensus (IPCC, 2007) on climate change makes its dismissal no longer tenable and the associated risk of making the world an even hungrier place unacceptable. Climate change impacts do not discriminate between the rich and the poor, nor do these make distinctions on where the severity of impacts will occur; all impacts are almost totally universal, with a degree of geographical variation. It is in the above context and in recognition of the importance and urgency of the issues related to climate change and its impacts that many global fora (e.g. United Nations Framework Convention on Climate Change, 1992; Kyoto Protocol, Kyoto, Japan, December 1997; Copenhagen Climate Change Conference, November 2009) have been convened, often bringing together global leaders, to explore potential mitigating measures and adaptabilities.

One of the greatest fears arising from climate change is its impacts on the world's food production systems. The gross predictions suggest there is going to be a reduction in agricultural productivity in the tropics and subtropics, hubs of population concentration and where most of the poor live (IPCC, 2007). If this is not addressed appropriately, it will have a bearing on the Millennium Development Goals (MDGs) (www.beta.undp.org/content/undp/en/home/mdgoverview.html), the most persuasive strategy to end world poverty and hunger. Aquaculture, like all production sectors, is not immune to the impacts of climate change.

Climate change impacts on food production have been considered on many occasions, and the broader aspects with regard to stressors on a growing

human population have been discussed in detail (e.g., McMichael, 2001). On the other hand, the climate change issues for the fisheries sector have received relatively little attention (Cochrane *et al.*, 2009), with the emphasis, if any, being on impacts on biodiversity and habitat (e.g. coral reefs). It is in this context that the fisheries sector as a whole has responded to improve its profile in the arena of climate change impact discussions, at all levels and relevant fora (Anon., 2009). Overall, there is a much better understanding of the impacts that climate change will have on the capture fisheries sector, particularly the marine fisheries; the latter still account for nearly two thirds of the global fish production.

It is estimated that fisheries and aquaculture support some 520 million people (approximately 8 percent of the current global population) for their livelihoods and incomes, and as the main source of animal protein. Allison *et al.* (2009) have suggested that the great bulk of the potentially affected are from vulnerable communities in tropical and low-lying areas and in small-island developing states. Furthermore, these are also among the world's poorest and twice as dependent upon fish for food as are those of other nations, with 27 percent of dietary protein derived from fish compared with 13 percent elsewhere (Allison *et al.*, 2009).

The general consensus on climate change impacts on capture fisheries is that even recent changes in the distribution and production of a number of fish species are ascribed to climate variability, such as the El Niño-Southern Oscillation. It is predicted that there could be an increase in production of 30 to 70 percent in high latitude regions (Cheung *et al.*, 2010) brought about by warming and reduced ice cover, but a decrease of 40 percent in production in low-latitude regions (Cheung *et al.*, 2010) as a result of reduced vertical mixing and hence the reduced recycling of nutrients (Brander, 2007). Brander (2007) also suggested that there could be negative impacts on inland fish production as a result of changes in precipitation patterns in certain areas. Until now there has been relatively little emphasis on climate change implications for aquaculture (Handisyde *et al.*, undated; De Silva and Soto, 2009), even though the sector is increasing in importance in global food fish supplies (FAO, 2009; Subasinghe *et al.*, 2009). For example, aquaculture currently accounts for 76 percent of global freshwater finfish production and 65 percent of mollusc and diadromous fish production (FAO, 2009) and is estimated to contribute approximately 50 percent to all seafood consumed (FAO, 2010).

Water is life. Aquaculture is synonymous with water, as it entails farming in waters – fresh, brackish and marine. Water stressors, of varying forms, are crucial to all food production, and these are being gradually addressed at both the global and regional levels, particularly by the larger countries. Vörösmarty *et al.* (2010) suggested that 80 percent of the world's population is exposed to high levels of threat to water security and that the poor nations remain very

vulnerable. These authors also pointed out that this vulnerability is associated with a lack of precautionary investment that jeopardizes biodiversity, with habitats associated with 65 percent of continental discharge classified as moderately to highly threatened; they thus called for a cumulative threat framework that offers a tool for prioritizing policy and management responses to this crisis. On the other hand, Piao *et al.* (2010), dealing with the climate change impacts on water resources and agriculture in China, showed that there are major changes taking place in river water flows, with significant regional differences within the country. For example, the authors indicated significantly reduced annual flows occurring in the Yellow River, thought to be at least partially brought about through climate change. These changes were shown to impact on agriculture, and most of the river deltas, being hubs of aquaculture activity, will also be impacted. It is important to note that there is a serious dearth of information linking the problems of water stress/availability brought about by climate change to impacts on aquaculture.

De Silva and Soto (2009) reviewed the climate change impacts on aquaculture. The present synthesis attempts to evaluate the challenges that climate change would impose on the sector. Accordingly, those facets of climate change that would impact on aquatic farming systems are considered, together with the ways and mechanisms that these impacts are likely to act. The Asia-Pacific region dominates global aquaculture (FAO, 2010); it is inevitable, therefore, that the main emphasis in this synthesis is on this region. Equally, it has to be appreciated that there are only a limited number of explicit studies of climate change impacts on aquaculture *per se*. Consequently, in some instances the synthesis also draws on the broader literature for examples of possible climate change impacts on aquatic farming systems.

Uniqueness of aquaculture

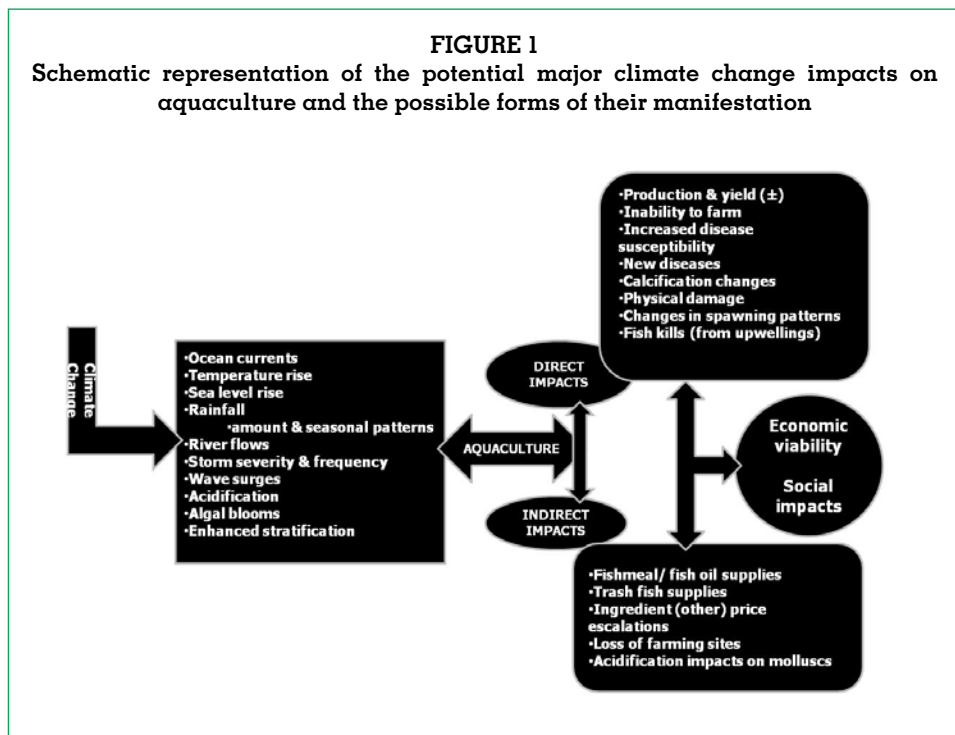
The great bulk of global food fish supplies, unlike all the other commodities, are of hunted origin. The change from a hunted supply to a farmed supply is only recent for most species, even though aquaculture is a millennia-old tradition for other species. Currently, aquaculture or farmed food fish supplies account for nearly 50 percent of the global food fish consumption (Subasinghe *et al.*, 2009; FAO, 2010), and its contribution is on the increase.

Unlike other farming sectors for animal protein, aquaculture is unique in that all the farmed animals are poikilothermic. It should also be noted that aquaculture includes the farming of plants, most notably seaweeds, for human consumption as well as industrial use. Aquaculture is also unique in the number of taxa farmed, which has been increasing over the years. In 2006, over 336 species of animals and plants, representing 115 families, were farmed, and the number is thought to be underestimated (Bartley *et al.*, 2009).

Finally, the commodities cultured are spread across a wide climatic range. Aquaculture is practiced in the tropics, subtropics, sub-temperate and temperate regions, literally extending from 40–45 °S to N. De Silva and Soto (2009) demonstrated that the current aquaculture activities, based on the four major commodities (viz. finfish, shrimp, molluscs and aquatic plants) are spread from south to north, and that the great bulk of aquaculture production occurs in tropical regions. They also demonstrated that there have been changes in the production profiles of the different climatic regions, in respect of each of the commodities, over the years. Perhaps some of these changes are driven by market changes; however, detailed treatment of these aspects is beyond the scope of the present review.

Potential impacts of climate change on aquaculture

Climate change impacts are manifested in many forms. The impacts on aquaculture can be direct or indirect, some impacts being what could be categorized as second-order impacts. The potential climate change facets that could have an impact on aquaculture together with the potential manifestations of climate change elements on aquaculture are schematically depicted in Figure 1. Those facets of climate change that influence, either directly and/or indirectly, are perhaps relatively easily discernible (Figure 1). It is also important to note that climate change facets could impact singly or in combination, and equally, some of the impacts may be hidden and not very obvious. Similarly, the impacts



may not be evenly distributed, being dependent on current climatic regimes. For example, temperature increases are likely to primarily influence those aquaculture activities which are located in temperate regions.

The main facets of climate change that could potentially impact directly or indirectly on aquaculture can be identified as:

- ocean currents;
- temperature changes;
- sea level rise;
- rainfall (amount and seasonal patterns);
- river flows;
- storm severity and frequency;
- wave surges;
- algal blooms;
- enhanced stratification;
- ocean acidification; and
- pests and diseases.

The above impacts are not arranged in any known order of importance of impacts on aquaculture, this being a relatively unknown factor. In the following section some of the above, either singly or in combination, and thought to be most relevant to this synthesis are dealt with.

Ocean currents

Impacts of climate change on ocean currents and the related follow-on effects on ocean productivity, fish population changes and migratory patterns, coral reefs and so forth are relatively well documented. Some of the more important changes that are predicted to occur are a loss in ocean biological productivity, or net primary productivity (NPP), that is translated through the food web to fish productivity (Brander, 2007). For example, it is estimated that productivity in the North Atlantic Ocean will plummet 50 percent and ocean productivity world wide by 20 percent (Schmittner, 2005). Cheung *et al.* (2010) further elaborated these predictions based on latitudinal difference, suggesting that high-latitude regions could experience a 30 to 70 percent increase in production as opposed to a decrease of about 40 percent in low-latitude regions.

The predicted changes in ocean circulation patterns, in turn, will result in the occurrence of El Niño-type influences being a more frequent possibility. The latter, in turn, will influence the stocks of small pelagics (e.g. anchovetta, *Engraulis ringens*), as had occurred in the past. Similarly, the changes in the North Atlantic Oscillation winter index (Schmittner, 2005) resulting in higher winter temperatures could influence sandeel (*Ammodytes* spp.) recruitment. These changes in oceanic current patterns and the associated events such as changes in ocean productivity are unlikely to impact on aquaculture directly, but will do so indirectly and to a very significant extent, as the above species

are a main raw material for the reduction (fishmeal and fish oil production) industry.

On the other hand, ocean currents could directly impact on aquaculture activities through bringing about changes in temperature (increases or decreases depending on the climatic region) causing stress effects and maybe even mortality. For example, in December 2009, such a cold current into Phuket Bay in Thailand reduced the water temperature by up to four degrees and is thought to have lead to mass mortality of cage-cultured brown-marbled grouper (*Epinephelus fuscoguttatus*) (personal observation).

Temperature changes

All cultured aquatic organisms are poikilothermic, and as such would be impacted by changes in water temperature. As previously mentioned, changes in water temperature could be brought about by alterations in circulation patterns which would impact on mariculture activities in particular. It is also important to note that the impacts of temperature changes (in particular, increases) are also linked to interactions involving declining pH and increasing nitrogen and ammonia, resulting in increased metabolic costs. For example, experimental studies on rainbow trout (*Oncorhynchus mykiss*) have shown that a 2 °C temperature increase improved appetite, growth, protein synthesis and oxygen consumption in the winter, but the reverse occurred in the summer (Morgan, McDonald and Wood, 2001). All this indicates the difficulty in predicting the climate change impacts on specific culture systems.

One of the main manifestations of climate change is often accepted as the global temperature increase, which in turn would result in water temperature increases. The temperature tolerance range of important cultured species in the temperate region in particular is close to the upper range of tolerance of these species (Table 1). An increase in temperature of a few degrees is likely to impact on the

TABLE 1
Temperature tolerances (°C) of selected, cultured species of different climate distribution

Climatic/temperature guild/species	Incipient lethal temperature		Optimal range
	Lower	Higher	
Tropical			
Redbelly tilapia (<i>Tilapia zillii</i>)	7	42	28.8–31.4
Guinean tilapia (<i>T. guineensis</i>)	14	34	18–32
Warmwater (subtropical)			
European eel (<i>Anguilla anguilla</i>)	0	39	22–23
Channel catfish (<i>Ictalurus punctatus</i>)	0	40	20–25
Temperate/polar			
Arctic char (<i>Salvelinus alpinus</i>)	0	19.7	6–15
Rainbow trout (<i>Oncorhynchus mykiss</i>)	0	27	9–14
Atlantic salmon (<i>Salmo salar</i>)	-0.5	25	13–17

Source: De Silva and Soto (2009), based on Ficke, Myrick and Hansen (2007).

culture and well being of such species. On the other hand, the situation is not so severe for cultured tropical species, because the predicted water temperature increases are likely to be still within the optimal range of tolerances.

Temperature increases in the temperate regions will also bring about negative, indirect impacts on aquaculture, such as inducing hitherto non-pathogenic organisms to become virulent and also increasing the range of distribution of pathogenic organisms. For example, it has been reported that mass mortalities of the tuberculate abalone (*Haliotis tuberculata*) in the Brittany and Normandy coasts were caused by the increased temperature and the presence of the pathogen *Vibrio harveyi*, and the resulting loss in reproductive potential (Travers *et al.*, 2009). Many such examples are known (for further details see, De Silva and Soto, 2009).

In the recent past, a high level of mortality has been recorded in Pacific cupped oyster (*Crassostrea gigas*) (<http://oceanacidification.wordpress.com/2009/06/15/oysters-in-deep-trouble>). Studies have demonstrated a link between the energy expended during reproduction and the compromised thermo-tolerance and immune status of oysters, leaving them easily subject to mortality if heat stress occurs in the post-spawning stage (Li *et al.*, 2007). The authors suggested that the findings improve the understanding of oyster summer mortality and its implications for the long-term persistence of molluscs under the influence of global warming.

Sea level rise

Sea level rise is considered as an important and significant result of climate change, impacting on coastal states and river salinities. Apart from general impacts on coastal communities and oceanic islands, the very existence of which are threatened, sea level rise will have major influences on aquaculture. Problems associated with sea level rise and consequent potential salinity intrusion are further exacerbated through reduced river flows, as well as by coastal land subsidence in certain areas.

Foremost is the impact on those agricultural and aquaculture activities in deltaic regions (Ericson *et al.*, 2006), particularly in the tropics, such as the Mekong Delta, Viet Nam and the Ganges-Brahmaputra Delta, Bangladesh, which are hubs of aquaculture activity, providing millions of livelihoods. In the deltaic regions of the tropics, the primary cultured species are shrimp and euryhaline finfish such as barramundi or Asian seabass (*Lates calcarifer*). However, the Mekong Delta (8°33'–10°55' N; 104°30'–106°50' E), aptly termed the “food basket” of Viet Nam (implicit in its importance to the total food supplies in the country as a whole), and the lower reaches of the Mekong River is the home to a thriving striped catfish (*Pangasianodon hypophthalmus*) farming industry, a truly freshwater finfish farming activity, (Phan *et al.*, 2009; De Silva and Phuong, 2011). This farming activity will be impacted over time due to increased seawater intrusion along the river, further exacerbated by reduced water flow,

with this catfish species unlikely to be able to tolerate the predicted salinity increases.

Rainfall, river flows and water stress

Rainfall patterns and quantity, river flows and water stress are intricately connected. In the tropics in particular, the monsoonal rain patterns and the associated changes in riverine habitats, etc. act as triggers for the maturation and spawning of many aquatic animal species, in contrast to the temperate regions, where the day-light cycle changes act as a primary stimulus (Welcomme, 1985). Furthermore, in the tropics most floodplain areas act as nursery grounds for a significant number of cultured finfish species (Welcomme, 1985) thus, losses in floodplain areas and the associated changes in the migratory patterns could bring about impacts on some ongoing aquaculture practices associated primarily with stock enhancement (Welcomme and Bartley, 1998).

Changes in monsoonal rain patterns and the total amount of rainfall have already been documented, and the impacts of some of these on terrestrial agriculture are well known (McMichael, 2001; Goswami *et al.*, 2006; Piao *et al.*, 2010). Overall, the predicted water stress is expected to result in decreased water availability in the major rivers in Central, South, East and Southeast Asia, as well as in Africa (IPCC, 2007), areas where major aquaculture activities are present, such as the major river deltas. Indeed, the predicted reduced water availability in the deltas of major Asian rivers has to be considered in conjunction with saline water intrusion arising from sea level rise (Hughes *et al.*, 2003) and the expected changes in precipitation/ monsoon patterns (Goswami *et al.*, 2006). De Silva and Soto (2009) summarized the possible impacts of the above climatic change factors on aquaculture. It is also important to note that eight of the ten major rivers in the world (O'Connor and Costa, 2004), based on basin area, peak discharge and unit runoff are found in the tropics, where aquaculture is predominant.

Storm severity and frequency, and wave surges

The frequency of extreme weather events such as typhoons, hurricanes and unusual floods has increased dramatically over the last five decades. For example, the number of such events increased from 13 to 72 in the decades 1950 to 1960 and 1990 to 2000, respectively (IPCC, 2007). These extreme events result in huge economic losses and for the above two decades, the mean annual losses have been estimated at between USD4 billion and USD38 billion (fixed dollars, 2000), and in some individual years in the latter decade were as high as USD58 billion (IPCC, 2007). Extreme climatic events, currently attributed to climate change (IPCC, 2007) are predicted to occur mostly in the tropical and subtropical regions.

All forms of aquaculture will be impacted by extreme events, primarily through destruction and damage to infrastructure, mostly outdoor structures such as

BOX 1. Asian aquaculture

The great bulk of Asian aquaculture is small scale. One of the important aquaculture developments in Asia is the small-scale aquaculture practices in coastal bays. These include an increasing number of seaweed farms and the small-scale cage culture of high-valued species such as groupers, wrasses and lobster. In the coastal areas, culture of milk fish (*Chanos chanos*), conducted traditionally in ponds (tambaks) using tidal exchange is also common. All these activities are conducted with relatively fragile infrastructure and are at high risk to storms, wave surges and high winds, and consequently the chances of livelihoods being impacted are also high.



pond dykes, which in turn will also bring about loss of stocks, including, for example, valued broodstock. On the other hand, most closed systems, which are generally more robust constructions, are likely to withstand most extreme events. Some of the recent extreme climatic events that have impacted on aquaculture were summarized by De Silva and Soto (2009); also see Soto, Jara and Moreno (2001), Muralidhar, Ponniah and Jayanthi. (2009). For example, during heavy storms in 1994–1995, salmon farms in southern Chile lost several million fish, mostly rainbow trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*) and Atlantic salmon (*Salmo salar*), all alien species which are commonly cultured in Chile (Soto, Jara and Moreno, 2001). The authors cautioned that such escapees could compete with indigenous species and that colonization and establishment in new habitats are possible.

There are many aquaculture practices that are small-scale and farmer owned/leased, operated and managed that occur in coastal regions throughout the Asia-Pacific. These small-scale practices contribute significantly to production, almost always providing the sole form of livelihood and food security to thousands. Wave surges and storm activities will bring about adverse impacts on these practices (Box 1).

Algal blooms and enhanced stratification

It is reported that in the oceans, there had been a noticeable drop in net primary productivity brought about by a combination of factors, mostly through warming and reduced nutrient mixing, particularly so in the lower latitudes (Brander, 2007). On the other hand, in inland waters climate change may bring about increased stratification of lakes and reservoirs in some areas. In stratified waters, changes in the weather conditions could bring anoxic waters from

the deeper layers, often also containing relatively high concentrations of toxic gases such as hydrogen sulphide, to the upper layers, impacting, for example, on cage farming and in extreme cases even resulting in fish kills (Abery *et al.*, 2005). Equally, eutrophication could be exacerbated and consequently could impact (mostly negatively) on food webs and habitat availability and quality (Ficke, Myrick and Hansen, 2007); in turn, both aspects could have a bearing on aquaculture activities, in particular for inland cage and pen aquaculture.

Ocean acidification

Ocean acidification is attributed to the increased atmospheric carbon dioxide from anthropogenic activities, a significant proportion of which ends up in the oceans (Cladeira and Wickett, 2003; Doney, 2006), resulting in a decrease in pH, carbonate ion concentrations (CO_3^{2-}) and the saturation states of calcium carbonate minerals such as calcite (Ω_{ca}) and aragonite (Ω_{ar}) (Cooley, Kite-Powell and Doney, 2009). It is believed that since the industrial revolution, the release of CO_2 from anthropogenic activities has resulted in the decrease of oceanic surface pH by 0.1 (Doney, 2006). Based on the prediction by IPCC (2007) that atmospheric CO_2 will range between 467 and 555 ppm by the year 2050, Cooley and Doney (2009) predicted that the surface ocean pH would drop by a further 0.3 and decrease global Ω_{ca} and Ω_{ar} by 25 percent relative to 2009. On the other hand, Caldeira and Wickett (2003) concluded that unabated CO_2 emissions over the coming centuries could produce changes in ocean pH that are greater than any experienced over the last 300 million years (Myr) and that a pH reduction of 0.7 is a possibility.

Decrease in pH of oceanic water from acidification is expected to impact on coral and calcareous skeletal formation, i.e. in corals, some planktonic organisms, molluscs, etc. The impacts of the above on marine ecosystems services were reviewed by Cooley, Kite-Powell and Doney (2009). In regard to aquaculture, the potential impacts could be varying, some even being unpredictable at present. The most likely impacts will be on mollusc culture; some of these are gradually becoming evident, such as the high level of mortality recorded in Pacific cupped oysters (<http://oceanacidification.wordpress.com/2009/06/15/oysters-in-deep-trouble/>) and reduced larval settlement due to improper calcification of the skeleton at metamorphosis. It has been suggested that ocean acidification may impact on the immune response of blue mussel (*Mytilus edulis*) through its influence on physiological condition and the functionality of the haemocytes, which could have a significant effect on cellular pathways, in particular those that rely on specific concentrations of calcium (Bibby *et al.*, 2008). In addition, data are being accumulated to suggest sub-lethal impacts of acidification on morphology, physiology and behaviour of molluscs, as well as gonadal development (Ishimatsu and Dissanayake, 2010). The above impacts are likely to bear on mollusc aquaculture globally, although admittedly to varying degrees in the different climatic regimes. Although ocean acidification is a reality, there are very few strategies available to reduce these impacts apart from adopting

mitigating measures to reduce atmospheric carbon dioxide levels, perhaps excepting the hatchery production of cultured molluscs, which could be carried out under controlled conditions.

Challenges for aquaculture

All of the above climate change elements could impact aquaculture directly and/or indirectly. As previously mentioned, such impacts cannot always be attributed to one single facet of climatic change, in most cases the impacts due to being a combination of many factors.

Direct impacts

Direct impacts of climate change events on aquaculture are those climate changes that would impact on farming activities where the impacts could be attributed to single or multiple facets of climate change.

Sea level rise

It is believed that exacerbated sea level rises are a direct impact of climate change. Sea level rises will impact on coastal regions, as well as deltaic areas, particularly of the tropics, where the increases in sea level are expected to be highest. As previously noted, most tropical deltaic regions, particularly those in the developing world, are hubs of farming activity (including aquaculture) that support millions of livelihoods.

Challenges to on-going aquaculture practices

Direct impacts of sea level rise will be through salinity intrusion and flooding, and will be mostly prevalent in deltaic areas. Sea level rise is expected to result in the slow flooding of aquaculture activities in areas such as in the Mekong Delta and the Ca Mau region, in southern Viet Nam. These are hubs of giant tiger prawn (*Penaeus monodon*) culture, including alternate rice culture in the wet season and shrimp culture in the dry season (Vuong and Lin, 2001). Similar situations occur in the Ganges-Brahmaputra Delta in Bangladesh and elsewhere.

The main challenge that the existing shrimp farming sector is likely to encounter is through flooding (with increased sea level making it harder to discharge flood waters). As a result of increased flooding, new water management schemes will have to come into being as a mitigating measure (Tan, 2008). In the process, there are likely to be conflicts between shrimp farmers and other stakeholders, and this will be a major challenge. Increased duration of flooding due to lowering of salinity below optimal level will also shorten the period available for shrimp culture and change the dynamics of the rice-shrimp culture systems. On the other hand, the situation will impact less on the shrimp farming in the Ganges-Brahmaputra Delta, as alternate rice-shrimp cropping is not practiced.

The predicted conditions that will be encountered by the striped catfish farming sector, a truly freshwater aquaculture activity, along the lower reaches of the Mekong River, Viet Nam will be in contrast to those anticipated for shrimp farming. This farming system provides nearly 180 000 livelihoods and is a major seafood export industry of Viet Nam (Phan *et al.*, 2009; De Silva and Phuong, 2011). With the predicted sea level rise of 3 mm/year, and concurrent with reduced river flow, seawater intrusion is predicted to cause increased salinity of up to 17–20 ppt along the river up to 70–80 km from its mouth. The current farming system relies on regular water exchange from the river that enables very high stocking densities to be maintained and high productivity averaging 250–400 tonnes/ha/crop (Phan *et al.*, 2009). Phan *et al.* (2009) have reported that catfish farms in the lowest reaches presently have a reduced productivity attributed to diurnal salinity fluctuations (to approximately 5 ppt) brought about by the tides. Consequently, as sea level rises over the years, catfish farms in the lower reaches will be subjected to significantly higher levels of salinity and are thus likely to become unproductive and economically unviable.

The major challenge therefore, is to retain the viability of this sector and safeguard the livelihoods of thousands through adoption of suitable strategies. One plausible strategy would be to develop a higher-salinity tolerant strain of striped catfish and disseminate the improved strain to farmers. This option will be a science-based solution and will necessarily involve extensive capacity building among farmers and a significant deviation from the current farming methods. This would involve selective breeding and protocols for transfer. The use of molecular genetic tools can reduce the time required to produce a salinity-tolerant strain, but such a development will also have to go hand in hand with relevant risk management measures, particularly in respect of potential impacts on biodiversity. On the other hand, the farmers may be given the choice to change to a different species, such as a salinity-tolerant barramundi or shrimp. Any such change will have to go hand in hand with changes in the whole farming system, capacity building among the farming community and major infrastructural changes, which will be exorbitantly costly.

New challenges

Salinity increases in deltaic regions in the tropics, hubs of agricultural and aquacultural activity (Ericson *et al.*, 2006) and the home to nearly 15 percent of the global population, will bring a major challenge to aquaculture but could also result in positive changes to some sectors of society. Saline water intrusion and associated flooding are likely to make a large acreage of current agricultural activities, primarily rice cultivation, untenable in such areas. However, such areas can continue to be utilized for aquaculture, thereby continuing to provide alternative livelihoods and much-needed food production.

As an example, the predicted changes in the Mekong Delta, literally the food basket of Viet Nam, accounting for 46 percent of the nation's agricultural

production and 80 percent of rice exports (Hö, 2008), are considered here. A one meter sea level rise is predicted to inundate 15 000 to 20 000 km², with a loss of 76 percent of arable land. Predictions by Khang *et al.* (2008) suggest that a 2.5 g/liter salinity front is likely to shift upstream by 10 to 20 km in the main river channel and by 20 to 35 km in the paddy fields by mid-2030. Overall, the simulations show that the area of triple rice crops will be reduced by 71 000 to 72 000 ha. Additionally, there are estimates that suggest that a one meter sea level rise will inundate 40 000 km² and displace 17.1 million persons from their normal livelihoods.

In the Ganges-Brahmaputra Delta in Bangladesh, inundation of 2 500, 8 000 and 14 000 km² have been predicted for 0.1, 0.3 and 1.0 m sea level rises, respectively (Handisyde *et al.*, undated). It has been shown that the Bengal delta area has one of the highest subsidence rates (Ericson *et al.*, 2006), and this, together with sea level rise, would have a compounded impact of loss of agricultural land. Increased salinization in the delta has been reported over the period 1973–1997, and this, with the expected sea level rise, suggests that the impacts are likely to be further aggravated (Handisyde *et al.*, undated). For example, the World Bank (2000) predicted a reduction of 0.5 million tonnes in rice production associated with a 0.3 m level sea level rise.

The major challenge confronting aquaculture, therefore, is to commence new farming systems in salinity-intruded areas. In order to meet this challenge, the planning processes have to be put in place soon. These processes would involve:

- making essential policy decisions on the need for a transformation of the farming systems and the livelihoods of the farmers;
- making a step-wise determination of the extent of inundation in relation to a time scale;
- determining the most suitable culture species, based on ecological, biological and potential market features;
- obtaining concurrence with the current farming communities on a potential shift in the livelihood pattern;
- planning the required infrastructural needs (e.g. hatcheries, pond nature and type) required to facilitate the transition; and
- providing the necessary capacity building in aquaculture practices to the farming communities through relevant extension and dissemination mechanisms.

The above steps of transformation of farming on land to farming in water will be a major change that may not necessarily be embraced easily and readily by all stakeholders. However, there appears to be no other easy option available to maintain livelihoods and food production. Obviously, the transformation will require determination to meet the varying range of challenges from all sectors, and a holistic approach to make it cost effective and efficient.

It is also possible that the above transformations could lead to new species emerging as major contributors to aquaculture production. After all, a decade back one would not have expected the striped catfish farmed in the Mekong Delta to impact upon the global aquaculture production and consequent food fish supply so significantly.

Changes in temperature

It has been clearly pointed out that temperature impacts on aquaculture can be direct or indirect, the latter being induced through different pathways, such as in relation to pathogens, changes to immune mechanisms, exacerbated post-reproductive stress and the like. Also in some instances, it will be a combination of climatic elements, including temperature, that could bring about impacts on aquaculture.

Among the major challenges to aquaculture triggered through temperature changes is a very direct one, whereby temperature rises in the temperate regions would approach and/or exceed the tolerance levels of some of the important cultured species such as salmonids. This challenge can be combated only through a shift to species with higher temperature tolerance, the development of strains of the currently cultured species with increased temperature tolerance range, and/or moving to intensive closed systems in which the environment is controlled.

It is generally conceded that the realization of the genetic potential of cultured aquatic animals and plants through selective breeding has lagged behind that of the animal husbandry sector. On the other hand, genetic improvements on salmonids, for example, have had major impacts on the culture of this group (Gjedrem, 2010). As such, it is expected that meeting the challenges confronting the production of strains of cultured salmonids with increased range of temperature tolerance would be possible, and it is heartening to note that the initial research on meeting these challenges has already been launched (Fish Farmer, 2008).

Seawater temperature increases in the temperate regions have resulted in the expression of virulence in pathogenic organisms that were relatively nonpathogenic at lower temperatures. These changes have resulted in an increase in the range of pathogens such as *Vibrio harveyi* (Travers *et al.*, 2009), posing new challenges to existing aquaculture operations, mainly mollusc culture. Similarly, as previously mentioned, in the recent past a high level of mortality has been recorded in Pacific cupped oysters.

These challenges have to be met by introducing adequate risk management measures, together with developing effective preventive measures, early diagnostic tools and new treatment profiles, as well as capacity building to adapt to changed farming systems.

Rainfall, river flows and water stress

The global freshwater supply is at a premium and is often considered as a primary commodity that could be limiting and to be conserved vigilantly (Falkenmark, Rockström and Karlberg 2009; Economist, 2010). For example, it has been pointed out that in the Asian continent, the backbone of global aquaculture, the amount of available freshwater per capita is the least among all continents (Nguyen and De Silva, 2006). In the context that freshwater finfish aquaculture is the leading subsector, globally, and that the Asia-Pacific region leads aquaculture production by contributing in excess of 90 percent to the global total (FAO, 2010), increased attention will have to be paid to the climate change impacts of changes in rainfall, river flows and water stress on aquaculture.

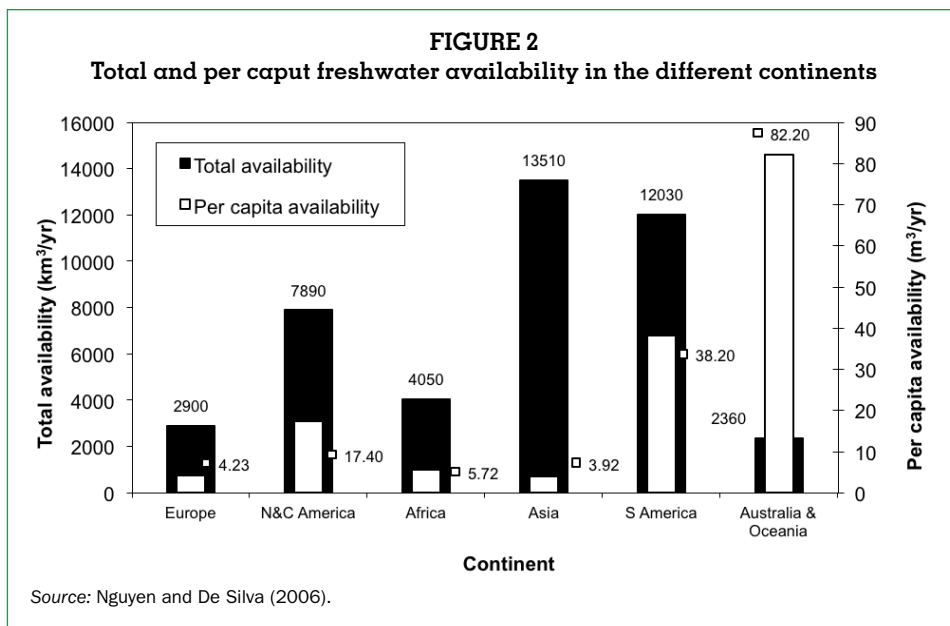
In general, and in the above context, water stress is likely to impact tropical aquaculture most (also see Allison *et al.*, 2009). The main challenges confronting the sector will be manifold. Changes in monsoonal rain patterns and consequent water availability will impact on a number of existing practices, and adaptive measures have to be put in place in order to maintain the current development impetus of the sector. For example, in most finfish cultured in the tropics, the spawning season is related to the rainfall pattern, even in the case of the bulk of hatchery-reared species, which are more often than not maintained outdoors. Equally, there is significant dependence on natural stocks for broodstock. There is emerging evidence that changes in rainfall regimes (and hence, flood regimes) have impacted on the breeding seasons of, for example, Indian major carps, in their natural habitats, with consequences on hatchery production (Vass *et al.*, 2009).

Thackery *et al.* (2010) pointed out that recent changes in the phenology (seasonal timing) of familiar biological events for all types of environments and taxa have been one of the most conspicuous signs of climate change. These authors further demonstrated the relationship of phenological changes and trophic levels. It is plausible that phenological changes will impact on cultured animals, in particular their reproductive seasonality, not only of those species that are artificially propagated but also those whose culture is based on natural spat and seed collection. These changes will impact the production cycles and the supply chains as a whole.

The aquaculture sector will have to evaluate the potential changes that may impact on the reproductive seasonality of the important cultured species. These evaluations should lead to adjustments in broodstock management, hatchery production and the production (grow-out) cycles for each of the major cultured species (also see Vass *et al.*, 2009).

Water availability

Our planet is estimated to have only 35 029 000 km³ of freshwater, or only 2.5 percent of all water resources, of which only 23.5 percent is useable



(Shiklomanov, 1993, 1998; Smith, 1998). The naturally available freshwater in the form of rivers, lakes, wetlands, etc. amounts only to 0.01 percent of the earth's water resources, or only 113 000 km³. The available water is not evenly distributed on the continents, and the amount available per caput (Figure 2) also varies among continents (Nguyen and De Silva, 2006). Even prior to climate change, impacts began to be manifested; water has been recognized as one of the most limiting resources on our planet (Falkenmark, Rockstöm and Karlberg, 2009; Economist, 2010). Consequently, issues related to present and future water requirements for humanity have been addressed many times, but almost totally in respect of terrestrial agriculture (e.g. Ward and Michelsen, 2002; Falkenmark, Rockstöm and Karlberg, 2009; Zimmer and Renault, undated; Piao *et al.*, 2010). Falkenmark, Rockstöm and Karlberg (2009) estimated the global water deficit by 2050 to be approximately 3 800 km³/year. On the other hand, fisheries–water issues have hitherto been scarcely addressed, having gained some attention only recently (Renwick, 2001; De Silva, 2003; Dugan, Dey and Sugunan, 2006).

Considering climate change impacts, the inland aquaculture sector, which currently contributes in excess of 60 percent of global aquaculture production, will need to strongly enhance management of freshwater resources if it is to maintain its significance in the coming decades.

Water recirculation technologies

Recirculation technology is not new (Hart and O'Sullivan, 1993; Losordo, Masser and Rakocy, 1998; McGee and Cichra, 2000) and it, in many diverse forms, is currently in use for many freshwater aquaculture systems and even

attempts are being extended to marine systems. Equally, the advantages of recirculation aquaculture are well documented, the foremost of these being saving on water, preventing and containing diseases, and providing biosecurity. However, recirculation systems are mostly used for the culture of high-valued species and/or the production of seed stocks of high-valued species such as shrimp. Recirculation systems entail high energy, capital and recurrent costs, and require skilled technical personnel for management.

The challenge to the use of recirculation systems will be to reduce the energy costs and thereby maintain the GHG emissions per unit production at an acceptable level, through engineering innovations. On the other hand, there is the possibility and the challenge of adopting outdoor recirculation systems that are less energy costly and are based on once-a-year water intake, but still provide the biosecurity and production capacities of indoor, high-tech systems. Such practices are currently in operation, for example, in Thailand and are utilized for the production of specific pathogen free (SPF) postlarvae of giant tiger prawn. Some of these enterprises have been very innovative, for example, some of the intermediate ponds in the system being used for the production of algae and finfish (barramundi), and with the tail end of the system producing *Artemia* biomass (approximately 100 kg/day), destined for the aquarium trade as a food source.

Water usage procedures

Currently, particularly in the tropics, large numbers of small-scale aquaculture practices tend to be clustered together in areas with access to water. Water is often abstracted for these aquaculture practices (e.g. pond culture) relatively freely and in an uncoordinated manner, independently of the surrounding aquaculture farms. Similarly, pond effluent is discharged to the primary water source in a uncoordinated manner. Indeed, from an environmental view point, the situation will be further exacerbated with higher scrutiny on the discharges. Added to all this is the general agreement that climate change will result in reduced water flow in many major river systems in the tropics (IPCC, 2007), further increasing the demand and competition for water for different primary production activities and farming systems (Falkenmark, Rockstöm and Karlberg, 2009).

As such, aquaculture dependent on common water resources has to develop suitable and appropriate water usage strategies. First and foremost, aquaculture farms in a given area abstracting water from a common source will need to coordinate water abstraction and discharge in a collective manner, with the goals of reducing the overall quantity abstracted and avoiding cross contamination via staggering of abstraction and discharge. Such coordination can be brought about through stakeholder consultations and concurrence on adoption of appropriate “water abstraction and discharge calendars” along river lengths (Umesh *et al.*, 2010). Development of such calendars will increase the efficacy of water

management and coordination with other users, in particular for agricultural purposes, enhance efficacy and lead to a net water saving.

The above should go hand in hand with development of better water management practices, which could be relatively easily incorporated in to better management practices (BMPs) that are being increasingly developed and adopted for specific cultured commodities through farmer cluster organizations (Umesh, 2007; Umesh *et al.*, 2010; www.enaca.org/modules/inlandprojects/index.php?content_id=1).

The ultimate challenge will be to increase vigilance and accountability on water use in freshwater aquaculture through the above processes. Perhaps this is best achieved through education and demonstration of water conservation strategies. An ecosystem approach to aquaculture (EAA) also offers an opportunity to address aquaculture planning with a clear consideration of the other coastal zone and watershed users (FAO, 2010). Clearly, aquaculture adaptation cannot take place in isolation from other users of common resources.

Culture based fisheries

Culture based fisheries (CBF) is considered an environmentally friendly aquaculture practice which is often rural and community based. It is a practice that is a good example of a secondary use of water resources for food fish production and can be conducted in small perennial and non-perennial water bodies (De Silva, 2003). This practice is being adopted by a number of developing countries (Lorenzen *et al.*, 1998; Quiros, 1998; Quiros and Mari, 1999; Song, 1999; Phan and De Silva, 2000; Amarasinghe and Nguyen, 2010) to improve the food fish supplies in rural communities and to improve farmer incomes, thereby improving prospects for food security. As the availability of small non-perennial water bodies in developing countries is rather high (e.g. in Asia alone, estimated at 66 710 052 ha; FAO, 1999), and as CBF is a low-cost aquaculture activity, it is attractive to many developing countries as a strategy to increase food fish production and improve rural livelihoods (Quiros, 1998; Quiros and Mari, 1999; Amarasinghe and Nguyen, 2010).

The bulk of inland water bodies suitable for CBF activities being rain fed, climate change impacts (as discussed previously) will have a bearing on both water availability and retention capacity. The challenge to CBF practices would be to assess the long-term availability and the relative suitability of such water bodies, as well as to determine the water retention periods appropriate for the stocked fish to attain a marketable size. In turn, the latter information needs to be used to estimate the fingerling (species wise) requirements for each growth cycle, and plan harvesting and marketing processes.

Algal blooms and enhanced stratification

In inland waters, particularly in lakes and reservoirs, cage culture is becoming increasingly important. Such activities are also adopted by governments to provide

alternative livelihoods to displaced communities, and they are known to have had much success in this regard (Abery *et al.*, 2005). Ficke, Myrick and Hansen (2007) suggested that climate changes could exacerbate eutrophication and produce more pronounced stratification in lentic systems, in the tropics in particular. Increased eutrophication could result in oxygen depletion in the dawn hours, and changes in wind patterns, rain fall, etc. could result in upwelling bringing deoxygenated deep/ bottom waters, often containing toxic gases such as hydrogen sulphide, to the surface, with adverse effects not only on cultured stocks but also on the naturally recruited fish stocks occurring in a water body. Similarly, in marine environments increased temperatures associated with eutrophication and harmful algal blooms (Peperzak, 2003) could enhance the occurrences of red tides and consequently impact on production, resulting in fish kills, and also increase the possibility of human health risks through the consumption of molluscs cultured in such areas. In particular, freshwater and marine cage culture in tropical areas tends to be located in enclosed bays and at high intensity.

The challenge for aquaculture is therefore, to ensure that high nutrient loads do not build up in the respective water bodies, and as far as possible, to spread out the activities into areas where the water circulation is better. In general, cage culture in reservoirs, lakes and enclosed bays tends to be concentrated in coves, primarily for ease of access to land facilities, transportation of feeds, marketing of produce, etc. Such areas also tend to have reduced water circulation and consequently act as “nutrient and waste sinks”, with the potential to bring about adverse impacts, as stated earlier. In the wake of climate change impacts with the potential to exacerbate algal blooms and upwelling of deoxygenated waters, it will be necessary to limit the concentration of aquaculture practices to restricted areas in a water body, and also to utilize areas with better water circulation at the expense of easy access to land-based facilities.

Aquaculture operations will have to adopt optimal stocking densities and feed management protocols, and act in unison rather than in single entities in a water body. It may, therefore, be necessary to come to agreement to reduce the density and the intensity of operations on a collective basis, in accordance with the potential carrying capacity of a water body. Where there has been nutrient build up over the years, the aquaculture operators, in conjunction with other stakeholders, will also need to adopt measures for nutrient stripping, for example, by the use of suitable planktivorous fish species, a form of stock enhancement which will also improve the livelihoods of fishers who are dependent on such water bodies, essentially moving towards a more pragmatic ecosystems approach to aquaculture development (FAO, 2010) that incorporates all aspects of watershed management.

Ocean acidification

The general impacts of ocean acidification on marine biota have been briefly discussed. Some direct impacts of ocean acidity on aquaculture are becoming

apparent, best exemplified by the decreased reproductive success of the Pacific cupped oyster in the last few years in Washington State, United States of America that has been attributed to ocean acidification (http://blogs.discovery.com/animal_news/2009/07/seems-like-theres-a-lot-of-bad-news-out-there-with-regards-to-the-worlds-oceans-this-time-the-bad-news-is-that-ocean.html). This lack of reproductive success, which commenced in 2004, has continued, not only in wild populations but also in hatchery stocks, which tend to use the same sea water, thereby impacting on the industry at large. Studies have shown that the impacts of acidification on reproduction in oysters are species specific. For example, it has been demonstrated that larvae of two closely related oyster species, the American cupped oyster (*Crassostrea virginica*), native to the western Atlantic, and the Suminoe oyster (*C. ariakensis*), both closely related to the Pacific cupped oyster, were very sensitive to elevated CO₂ (i.e. reduced pH or more acidic water). On the other hand, Suminoe oyster populations, native to the western Pacific, were apparently not affected by changes in CO₂ levels (Miller *et al.*, 2009).

Extreme weather events

One of the biggest challenges that will be encountered, not only for aquaculture but for all forms of human endeavour, is the occurrence of extreme weather events. The unpredictability of the nature, frequency and intensity of extreme weather events poses challenges to planning to combat such events. There are few means available to meet these challenges except to know well the risks and take precautionary measures (e.g. improve the physical strength of infrastructure facilities, provide facilities to minimize loss/escape of stocks) so that the impacts, if any, are kept at a minimum. Equally important is that measures are put in place so that activities can be revitalized after the event with the least degree of hardship. The siting of new facilities and maintenance of natural barriers such as, for example, mangrove, forest and reef belts will provide an extra degree of protection to withstand calamities from extreme weather events.

The major challenge is to develop suitable policy guidelines that would ensure increased risk assessment and improved preparedness, such as that aquaculture facilities in the most vulnerable areas will be constructed to comply with minimal requirements to withstand identified extreme climatic events, and that such facilities also incorporate all possible measures to prevent the escape of stock into the wild. The latter policy could be further strengthened in respect of those facilities that culture alien species. Governments are faced with the challenge of providing suitable policies and incentives to small-scale farmers to take insurance so that practices could be revitalized after such events with minimal economic hardship. In this regard, governments need to pursue the possibility of providing insurance facilities to “farm clusters” – farms organized into legalized, cooperative entities – thereby reducing the burden on individual farmers. This may become acceptable to financial institutions, as had been demonstrated in the case of small-scale shrimp farmers in India (Umesh *et al.*, 2010).

Indirect impacts

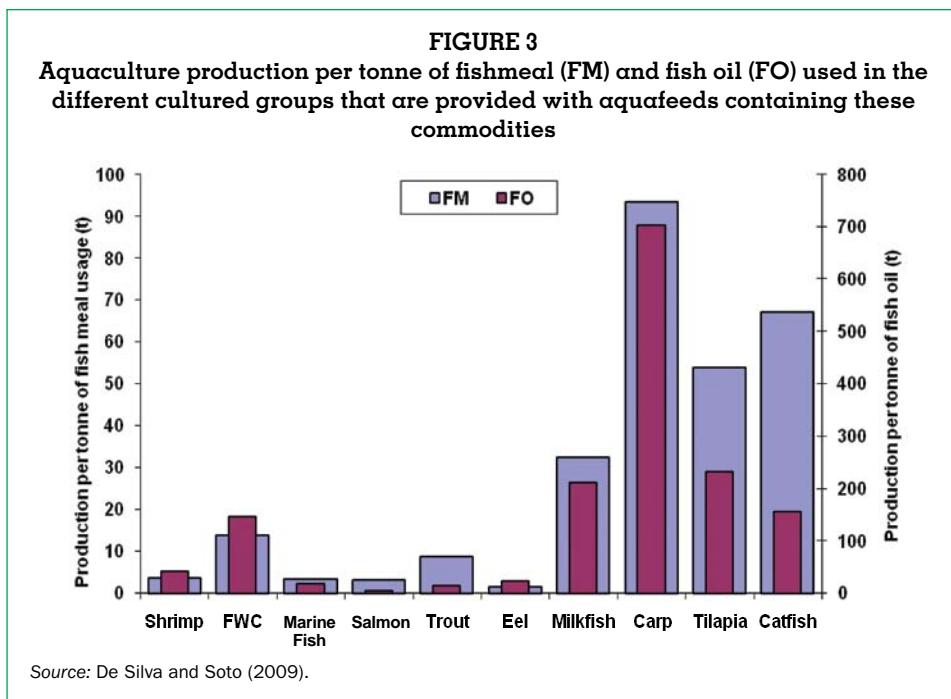
It was estimated that aquaculture in 2006 used 3 724 000 of fishmeal and 835 000 tonnes of fish oil, accounting for 68.2 and 88.5 percent of global production of these commodities, respectively (Tacon and Metian, 2008). Jackson (2010) suggested that fishmeal usage in aquaculture was 58.8 percent of the global production and predicted that 76 percent of the global supply of fish oil would be used in 2010. Irrespective of these estimates, as well as other controversies associated with fishmeal and fish oil usage (e.g. Naylor *et al.*, 2000; Aldhous, 2004; De Silva and Turchini, 2008), it has to be conceded that aquaculture will continue to remain a very significant user of global fishmeal and fish oil.

It has been previously mentioned that ocean net productivity is likely to decrease in the wake of climate change, and specifically, some of the fish populations that provide the basic raw material for the reduction industry are likely to decrease. Added to this reduction in the available raw material base, the growing public pressure on the use of a potential human food source for animal feed production purposes is likely to intensify, as MDG on poverty reduction appear unlikely to be attained within the originally stipulated time frame.

Accordingly, aquaculture, as it expands and intensifies, will have to confront the challenge of coping with a potential reduction of fishmeal and fish oil supplies. Many strategies have been suggested and are being attempted in this respect. The major ones include a reduced usage of fishmeal and fish oil in aquafeeds through the use of alternative ingredients, the possible genetic manipulation of cultured fish species to induce the capability to elongate and desaturate base fatty acids into highly unsaturated fatty acids (HUFA), better feed management and so forth. It is also important to note that the return of food fish per tonne of fishmeal or fish oil used (Figure 3) differs widely between cultured species; omnivorous species such as carps and tilapias are many times more productive than carnivorous species (salmonids, eels, etc.). It is conceded, however, that there is an increasing trend for the production systems for the former species to shift to use of pelleted feeds containing fishmeal (but very little fish oil), which could change the balance to some degree. All in all, what is needed are improved feed management strategies for all cultured species, which unfortunately has not received the attention it should.

Aquaculture will not only have to find technological solutions, including genetic manipulation, but also management strategies to significantly reduce the use of fishmeal and fish oil. In the wake of climate change impacts and other global aspirations, in order to do so and achieve long-term sustainability, the sector will have to adopt a fresh paradigm.

In the preceding sections, adaptive strategies were suggested to combat climate change impacts, including the development of new strains specific to certain



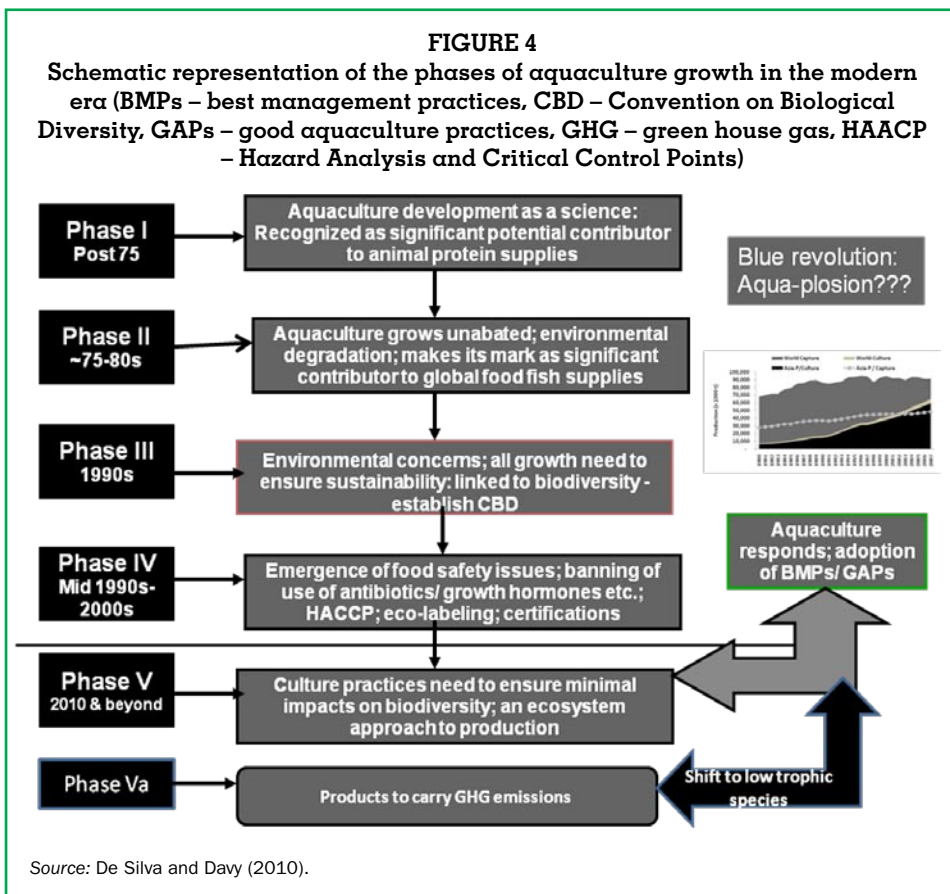
farming systems. Development of strains having, for example, increased salinity tolerance or increased temperature tolerance is not only technologically feasible but could be done relatively rapidly compared to the time taken in the past using technologies such as genomic selection (Meuwissen, Hayes and Goddard, 2001). The development of new strains should, however, go hand in hand with appropriate risk management strategies to minimize escapes into the wild that may impact on the gene pools of wild stocks, either directly or indirectly.

Aquaculture in some regions is dependent, to varying degrees, on alien species (Gajardo and Laikre, 2003; De Silva *et al.*, 2006, 2009). The use of alien species in aquaculture is often cited as impacting biodiversity, particularly in freshwaters (e.g. Moyle and Leidy, 1992; Naylor, Williams and Strong, 2001). In extreme weather events, it is possible that broodstock of such cultured alien species could be lost, as was the case in southern China when a very cold spell of weather caused the loss of large stocks of tilapia. In such instances, broodstocks will need to be replenished to sustain those farming systems, preferably using animals of the same origin as the founder stocks. In view of emerging international protocols and access and benefit-sharing issues (Bartley *et al.*, 2009) on genetic resources, such procurements may not be easy or straightforward, even if proper risk analyses are undertaken. As such, there may be need for these emerging protocols to consider introducing clauses that would facilitate rather than hinder the exchange of genetic resources in such special circumstances.

Mollusc culture is typically conducted in “open water” where there is free intermingling with the wild biota. Equally, in some areas it is still dependent on wild spat. Although genetic solutions, through the development of strains to regain spawning potential and/or disease resistance are possible, the question arises as to the use of these strains in open waters. There are no easy answers to this problem, and global agreements will have to be pursued to address these issues.

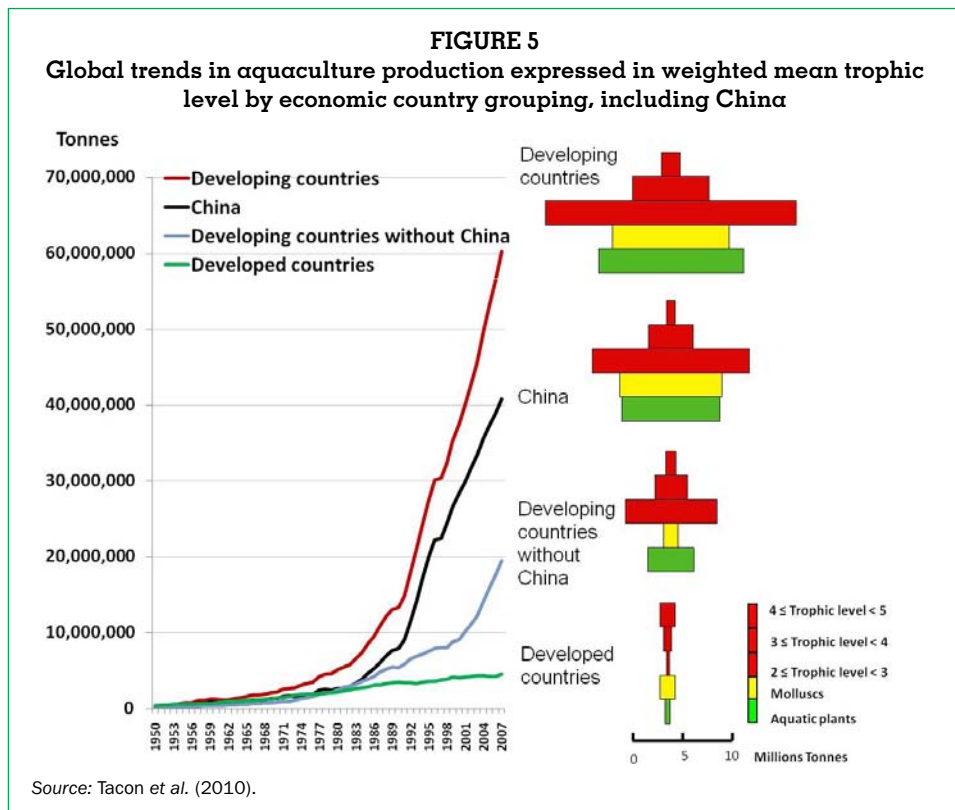
The major challenge of a paradigm shift

Aquaculture, a millennia-old tradition, became a significant food production sector relatively recently. It is cited as the fastest-growing food production sector in the last three decades, and is still in a growth phase (Subasinghe *et al.*, 2009). De Silva and Davy (2010) attempted to conceptualize the growth phases of modern aquaculture, as depicted in Figure 4. In this depiction, it is predicted that in the coming era the driving consumer force and aspiration will be an assessment of the green house gases (GHG) emitted from farm to fork, the emerging consumer opting for food types that are minimally GHG emitting.



Tacon *et al.* (2010) demonstrated that the aquaculture sector is essentially comprised of two broad groupings: developing countries (with and without China) and developed countries. These authors went on to show that aquaculture production within developing countries has focused, by and large, on the production of lower trophic-level species (e.g. carps, tilapias and catfishes), while developed countries have focussed mainly on the culture of high-value, high-trophic-level, carnivorous fish species (Figure 5). In essence, the latter is almost equivalent to providing food fish positioned high in the aquatic food chain, as in the case of many marine capture fisheries. As had previously been discussed, the long-term sustainability of these production systems is questionable unless the industry can reduce its dependence upon capture fisheries for sourcing raw materials for feed formulation and seed inputs (Tacon *et al.*, 2010). Sustainability issues, exacerbated by changing consumer preferences for eco-friendly food types, primarily measured through GHG from farm to fork, will necessarily be a major challenge to the aquaculture sector. This challenge calls for a major paradigm shift in the sector, perhaps the only option available to it in the coming decades.

A paradigm shift is a challenge that is not easily achievable, as it will entail major changes in farm management, as well as commercial and market-chain changes, which will entail a shift to increased preference for consumption of commodities



lower in the food chain. Such a shift, of course, will encounter resistance from certain quarters, including some producers. However, a paradigm shift does not necessarily have to be a total “black or white” solution. The shift can, in the early stages at least, be gradual but entail a long-term global consensus and a desire to bring the shift to fruition, as far as possible.

Conclusions

Climate change impacts and the challenges that the aquaculture sector faces in the wake of these are summarized in Table 2. Clearly, the situation and the issues are not straightforward, and aquaculture, as well as other food production sectors, will have to address many compounding impacts and corresponding challenges. Equally, challenges, adaptations and mitigating measures are also interactive; they are often difficult to discern from each other, leading to the conclusion that a more holistic approach is needed to meet these challenges. Climate change impacts on aquaculture are varying and are both direct and indirect. The challenges that aquaculture confronts need both technological and

TABLE 2

A summary of the important impacts of the different elements of climate change on aquaculture and the potential challenges these impacts may present to aquaculture. (FW – freshwater, M – marine) ¹

Aquaculture/other activity	Impact(s)		Challenges
	+/-	Type/form	
All; cage, pond; finfish (temperate regions)	-	Rise above optimal range of tolerance	Selective breeding for higher temperature tolerance; other options needed
All; cage, pond; finfish (tropical regions)	-	Sudden occurrence of cold currents/weather	Vigilance; be prepared to move stock
All; tropical finfish	+	Increase in growth; higher production	Meet increasing feed demands
FW; cage	-	Eutrophication & upwelling; stock mortality	Better siting, conform to carrying capacity, need to reduce intensification; use stock enhancement practices for nutrient stripping; regulate monitoring
M/FW; mollusc (temperate)	-	Increased virulence of pathogens; new diseases & increase in the range of others	Monitoring to prevent health risks; develop prophylactic measures; improvise proper risk management when using specially developed pathogenic resistant strains in open water culture
Carnivorous finfish/shrimp ²	-	Limitations on fishmeal & fish oil supplies/price	Fishmeal & fish oil replacements; improve feed management; shift to non-carnivorous culture commodities
Artificial propagation of species for the “luxurious” live fish restaurant trade ²	(+)	Coral reef destruction	Continue development of artificial propagation techniques; reduce dependence on wild seed supplies; impress upon the public the indirect impacts on biodiversity conservation through aquaculture
Sea level rise, ocean productivity reduction and other circulation changes			
All; primarily in deltaic regions in the tropics	+/-	Saltwater intrusion; flooding	Develop salinity-resistant strains for some; reduce possible conflicts with other users; develop a holistic approach to water management
	+/-	Loss of agricultural land	Provide alternative livelihoods –aquaculture: capacity building and infrastructure

TABLE 2 (Continued)

Aquaculture/other activity	Impact(s)		Challenges
	+/-	Type/form	
Fishmeal and fish oil supplies	-/+	Reduction & high cost	Find alternatives to fishmeal & fish oil; genetic manipulation to enable fatty acid chain elongation & desaturation; paradigm shift to transform aquaculture to omnivorous & herbivorous species
Shellfish	-	Increase of harmful algal blooms (HABs)	Alertness; risk assessment on culture sites
Acidification			
Mollusc/seaweed culture (primary impact in temperate waters)	-	Impact on calcareous shell formation	To use areas of least acidification potential
Water stress (and drought conditions, etc.)			
Pond culture	-	Water abstraction & discharge	Improve efficacy of water usage by introducing water calendars; initiate collective action along river lengths; incorporate water use & management into better management practices (BMPs); encourage non-consumptive water use in aquaculture (e.g. culture based fisheries (CBF); improve energy efficacy of recirculation systems; popularize open, small-scale, less energy-demanding recirculation systems
Culture based fisheries	-	Water retention period reduced	Model water regimes & determine the extent of water bodies usable for CBF; use fast-growing fish species; increase efficacy of water sharing with primary users (e.g. irrigation of rice paddies)
Riverine cage culture (tropical/artisanal)	-	Availability of wild seed stocks reduced/ period changed	Use artificially propagated seed
Extreme climatic events			
All forms; predominantly coastal areas	-	Destruction of facilities; loss of stock; loss of business; large-scale escapes with potential impacts on biodiversity	Develop suitable policies to strengthen physical facilities; policies to make insurance available to all culture activities irrespective of scale, including group/cluster insurance
Changes in fishmeal and fish oil supplies, general consumer aspirations for less green house gas (GHG)-emitting food types (from farm to fork)			
All aquaculture	+	General problem of feed availability & high cost & market demand for reduced GHG emissions in food production	To make a paradigm shift through increasing the culture of commodities that need lower protein feeds; encourage culture of herbivorous & omnivorous species

¹ Source: Modified from De Silva and Soto (2009).

² Instances where more than one climate change element will be responsible for the change.

adaptive approaches. By and large, the adaptive approaches dominate in this regard. Bearing in mind that the great bulk of aquaculture practices occur in the tropics and are mostly small-scale operations that are often clustered in areas conducive for the practices, the challenge is to bring all stakeholders together for collective action to adopt relevant measures. For example, in previous sections, it was pointed out that the challenges to the sector lie in developing “water calendars” and in reducing the density (stocking density as well as farm density) and intensity of culture. These challenges can be met and the practices sustained only through collective action among all stakeholders. Meeting the

challenges posed by climate change requires both political will and relevant policies to guide the actions.

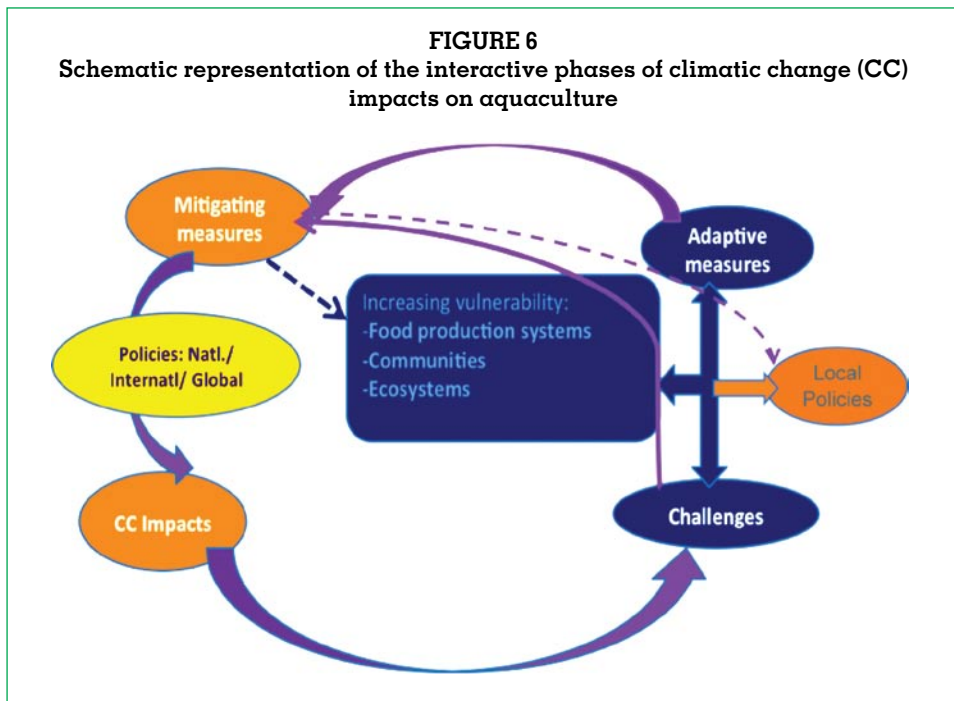
There are other potential climate change impacts for which the challenges posed to the sector have very few options available. Foremost of these is the impact of extreme weather events, where the degree of predictability and intensity are also very low. Here again, there is a need for political will and effective associated policies to be put in place.

There is a unique challenge likely to confront aquaculture as a result of climate change impacts, at least in certain population hubs of the developing world, albeit at the expense of current livelihoods; the challenge of adopting an alternative livelihood to agriculture such as rice farming though aquaculture, in areas that will be made unsuitable for rice farming. This challenge can be met with major success only if preparations, in respect of acceptance of the strategy to utilize aquaculture development as an alternative livelihood opportunity are done well in advance. This major challenge of transformation from agriculture to aquaculture will not be smooth nor easy; it will involve millions of people and their families, giving up old traditions and thereby inflicting substantial cultural changes in communities – hence the very reason to start the processes early. Apart from the direct technological challenges that climate change impacts will pose to the aquaculture sector, all the other challenges will have to be addressed in a holistic manner, in cooperation with related production sectors, primarily agriculture. On the positive side, therefore, is the potential to bring sectors together and develop common strategies, such as those for addressing the situation of water stress. This is a major challenge for all, and the degree of effectiveness of this strategy will perhaps be pivotal to all of the primary production sectors, all of which are dependent on two of the most limiting physical resources on our planet – land and water.

Aquaculture became a globally significant food production sector only in the last three to four decades. It is a sector that is gradually reducing our dependence on hunted food sources. Its major developments took place and continue to take place in an era when public perceptions on development have had a major shift, where sustainability and environmental integrity have become crucial and indeed essential elements of development, and also in an era where the public is often misinformed (De Silva and Davy, 2010). It is not surprising that all this has lead to a continued scrutiny of the sector. The major challenge now confronting aquaculture is to convince the public that it is an important production sector that can contribute significantly to mitigating climate change impacts through the production of food types that are minimally GHG emitting and some commodities which are carbon sequestering. As previously discussed, a corresponding paradigm shift together with the above will facilitate the need to meet climate change impacts through political will and associated policy changes.

It is also important to point out that the aquaculture sector when proposing strategies to meet the challenges of impacts of climate change should develop holistic approaches that take into consideration potential secondary influences. A case in point is the advocacy of the use of krill for reduction as a partial substitute for fishmeal and fish oil (Olsen *et al.*, 2006; Suontama *et al.*, 2007). However, it is becoming increasingly apparent that krill populations, which are a main food source of highly protected marine mammals, the whales, are being impacted significantly by climate change. In this regard, Atkinson *et al.* (2004) demonstrated that there had been a decrease in the density of Antarctic krill (*Euphausia superba*) and correspondingly, an increase in salps (mainly *Salpa thompsonii*), one of the main grazers of krill. This trend is likely to be exacerbated by climatic changes, sea temperature increases and the decrease in polar ice. The situation is being further exacerbated by the fact that reduction of the polar ice cover has enabled the fishing season for krill to be extended, and it has been suggested that this extension may have compounding impacts on krill populations (Kawaguchi, Nicole and Press, 2009). In summary, this alternative may not be an option to meet the challenge of reducing fishmeal and fish oil content in aquafeeds.

Certain possible strategies to combat climate change impacts through the application of genetic technologies may pose problems, and such use will have to be balanced against potential impacts on the gene pools of wild organisms. Finally, all adaptive and mitigating measures need to be interactive and cannot stand alone (Figure 6); even straight-forward technological developments can be applied through a holistic approach.



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Part III – Expert Panel Reviews



...the way, of...
...to be your friends...
...with you...
...tell you what to think and how...
...never quantify what you know...
...take a look around...
...we not running anyone...
...we in the...
...we're ready for the war... for the war

Responsible use of resources for sustainable aquaculture

Expert Panel Review 1.1

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Abstract

Comparisons of production, water and energy efficiencies of aquaculture versus an array of fisheries and terrestrial agriculture systems show that non-fed aquaculture (e.g. shellfish, seaweeds) is among the world's most efficient mass producer of plant and animal proteins. Various fed aquaculture systems also match the most efficient forms of terrestrial animal husbandry, and trends suggest that carnivores in the wild have been transformed in aquaculture to omnivores, with impacts on resource use comparable to conventional, terrestrial agriculture systems, but are more efficient. Production efficiencies of edible mass for a variety of aquaculture systems are 2.5–4.5 kg dry feed/kg edible mass, compared with 3.0–17.4 for a range of conventional terrestrial animal production systems. Beef cattle require over 10 kg of feed to add 1 kg of edible

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weight, whereas tilapia and catfish use less than 3 kg to add a kg of edible weight. Energy use in unfed and low-trophic-level aquaculture systems (e.g. seaweeds, mussels, carps, tilapias) is comparable to energy use in vegetable, sheep and rangeland beef agriculture. Highest energy use is in fish cage and shrimp aquaculture, comparable to intensive animal agriculture feedlots, and extreme energy use has been reported for some of these aquaculture systems in Thailand. Capture fisheries are energy intensive in comparison with pond aquaculture of low-trophic-level species. For example, to produce 1 kg of catfish protein about 34 kcal of fossil fuel energy is required; lobster and shrimp capture fisheries use more than five times this amount of energy. Energy use in intensive salmon cage aquaculture is less than in lobster and shrimp fishing, but is comparable to use in intensive beef production in feedlots. Life Cycle Assessment of alternative grow-out technologies for salmon aquaculture in Canada has shown that for salmon cage aquaculture, feeds comprised 87 percent of total energy use, and fuel/electricity, 13 percent. Energy use in land-based recirculating systems was completely opposite: 10 percent of the total energy use was in feed and 90 percent in fossil fuel/electricity. Freshwater use remains a critical issue in aquaculture. Freshwater reuse systems have low consumptive use comparable to vegetable crops. Freshwater pond aquaculture systems have consumptive water use comparable to pig/chicken farming and the terrestrial farming of oil seed crops. Extreme water use has been documented in shrimp, trout, and striped catfish operations. Water use in striped catfish is of concern to Mekong policy-makers, as it is projected that these catfish aquaculture systems will expand and even surpass their present growth rate to reach an industry of approximately 1.5 million tonnes by 2020.

Water, energy and land usage in aquaculture are all interactive. Reuse and cage aquaculture systems use less land and freshwater but have higher energy and feed requirements, with the exception of “no feed” cage and seawater (e.g. shellfish, seaweeds) systems. Currently, reuse and cage aquaculture systems perform poorly in overall life cycle or other sustainability assessments in comparison to pond systems. Use of alternative renewable energy systems and the mobilization of alternative (non-marine) feed sources could improve the sustainability of reuse and cage systems considerably in the next decade.

Resource use constraints on the expansion of global aquaculture are different for fed and non-fed aquaculture. Over the past decade for non-fed shellfish aquaculture, there has been a remarkable global convergence around the notion that solutions to user (space) conflicts can be solved not only through technological advances, but also by a growing global consensus that shellfish aquaculture can “fit in”, not only environmentally but also in a socially responsible manner, to many coastal environments worldwide, the vast majority of which are already overcrowded with existing uses.

For fed aquaculture, new indicators of resource use have been developed and promulgated. Before this resource use in fed aquaculture was being measured in terms of feed conversion ratios (FCRs) followed by FIFO (“fish in fish out”) ratios. First publications a decade ago measured values of FIFO in marine fish and shrimp aquaculture. More comprehensive indicator assessments of fish feed equivalencies, protein efficiency ratios and fish feed equivalences will allow more informed decision-making on resource use and efficiencies. Over the past decade, aquafeed companies have accelerated research to reduce the use of marine proteins and oils in feed formulations, and have adopted indicators for the production efficiencies in terms of “marine protein and oil dependency ratios” for fed aquaculture species. Current projections are that over the next decade, fed aquaculture will use less marine fishmeals/oils while overall aquaculture production will continue its rapid growth.

Over the past decade, new, environmentally sound technologies and resource-efficient farming systems have been developed, and new examples of the integration of aquaculture into coastal area and inland watershed management plans have been achieved; however, most are still at the pilot scale commercially or are part of regional governance systems, and are not widespread. These pilot-scale models of commercial aquaculture ecosystems are highly productive, water and land efficient, and are net energy and protein producers which follow design principles similar to those used in the fields of agroecology and agroecosystems. Good examples exist for both temperate zone and tropical nations with severe land, water and energy constraints.

Increasing technological efficiencies in the use of land, water, food, seed and energy through sustainable intensification such as the widespread adoption of integrated multi-trophic aquaculture (IMTA) and integrated agriculture-aquaculture farming ecosystems approaches will not be enough, since these will improve only the efficiency of resource use and increase yields per unit of inputs and do not address social constraints and user conflicts. In most developing countries, an exponentially growing population to 2050 will require aquaculture to expand rapidly into land and water areas that are currently held in common. Aquaculture expansion into open-water freshwater and marine waters raises the complex issues of access to and management of common pool resources, and conflicts with exiting users that could cause acute social, political and economic problems. The seminal works of 2009 Nobel Laureate Elinor Ostrom could provide important insights for the orderly expansion of aquaculture into a more crowded, resource-efficient world striving to be sustainable, and rife with user conflicts.

KEY WORDS: *Aquaculture, Production efficiency, Responsible resource use, Sustainability.*

Introduction

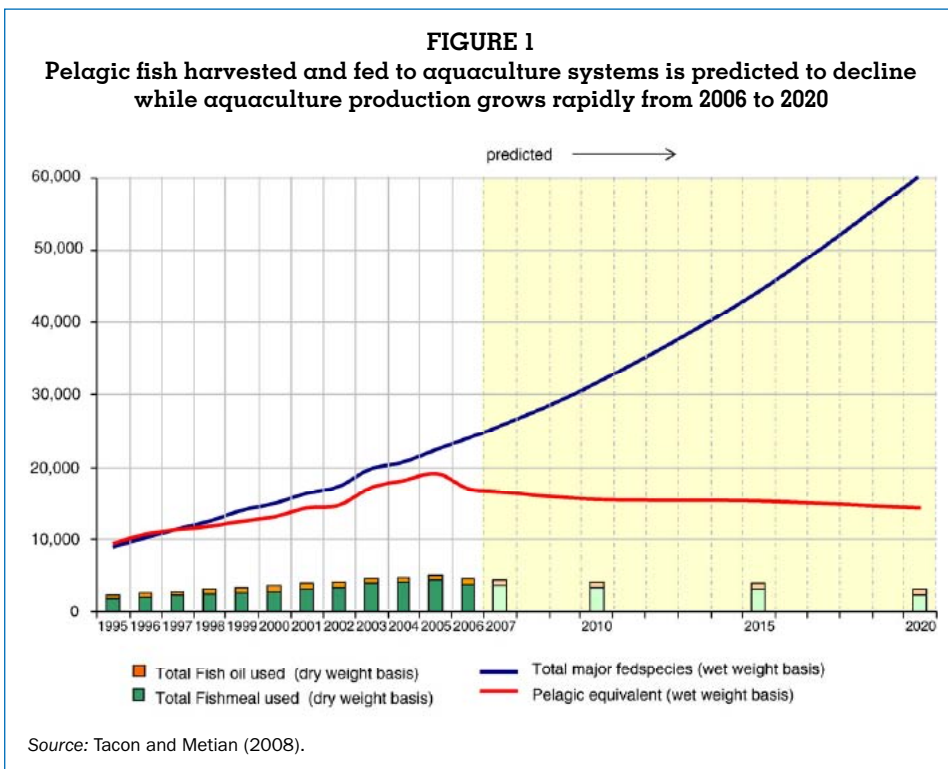
Today, about 1.3 billion people live on less than a dollar a day, and half of the world's population lives on less than two dollars a day (World Bank, 2008). A billion people are undernourished and in poverty, with an estimated 97 percent of them residing in Africa and Asia. By 2050, the world's population will rise from its current level of 6.8 billion and plateau at approximately 9 billion, with nearly all population growth occurring in economically developing countries (Godfray *et al.*, 2010). The World Bank (2008) has estimated that the world will need 70–100 percent more food by 2050, and will need to feed 2.3 billion poor, requiring food production to increase by approximately 70 percent from its current levels (FAO, 2009). Today, in ten African countries where aquatic proteins are a vital dietary component, having an estimated 316 million persons, 216 million live on USD2 per day, 88 million are undernourished and 16 million children under age five are malnourished (Allison, Beveridge and van Brakel, 2009).

On top of this population poverty crisis are scientific predictions of alarming environmental problems for both Asia and Africa. The United Nations Framework Convention on Climate Change (2007) predicts that a 2 °C temperature increase could lead to a 20–40 percent decrease in cereal yields in Asia and Africa. Lele (2010) believes that unless the global architecture of agricultural investments, research and development is changed over the next several years that the Millennium Development Goal of reducing hunger by 2015 will not be met. Aquaculture can play a major role in delivering high-quality, energy and protein-rich foods to the world's poor, in economic development and in overall poverty alleviation. However, as pointed out by Edwards (2002), “There is a need for a paradigm shift in philosophy away from food for the poor, which addresses the symptoms of poverty, not causes, to creation of wealth.” Massive decreases in poverty due to wealth creation by aquaculture have occurred in China, Bangladesh, India and Viet Nam in the past ten years (Edwards 2002; Phan *et al.*, 2009). In Chile, the employment that is generated by the salmon aquaculture industry has a positive and direct impact on the poverty indicators of communities where this industry is developed (Bórquez and Hernández, 2009). However, in order to provide additional high-energy aquatic foods for people to 2050, important flows of natural resources will need to be understood, measured, used and allocated more efficiently globally, regionally and locally, which could result in the reallocation of resources more consciously into the most efficient animal and plant production systems for food production. Food production will also need to be conducted in a way that reduces poverty, takes into account natural resource limitations, moves towards full cost accounting, resolves conflicts and generates wealth.

There have been concerns that aquaculture has been moving away from its global responsibility to be more “sustainable” and to realize its altruistic goals of providing net benefits (additional foods) for a protein-hungry planet. Wurts

(2000) stated that “Whether the word sustainability has become overused or not, it has catalyzed a forum for oversight of the growth and development of aquaculture on a global scale.” Fed aquaculture has been criticized for its resource subsidies which have fueled the expansion of aquaculture systems that can be net resource losers and, as a result, some workers have called for full accounting of resource flows and for better planning for aquaculture as part of the global effort to provide additional foods but to also maintain essential ecosystems, goods and services (Folke, Kautsky and Troell, 1994; Goldberg and Naylor, 2005; Alder *et al.*, 2008; Naylor *et al.*, 2009). Greater than 75 percent of global fisheries are traded, while only 7 percent of meat, 17 percent of wheat and 5 percent of rice is traded. In 2000, more than 60 percent of fishmeal was traded. Current projections are that over the next decade to 2020, fed aquaculture will use less marine fishmeals/oils while overall aquaculture production will continue its rapid growth (Figure 1). Concerns about the trajectories of resource use and subsidies in aquaculture have intensified as international trade in fisheries and aquaculture products and the essential resources to sustain them have increased dramatically.

Scientists and policy-makers agree that ecologically sound farming systems that include aquaculture as part of more resource-efficient, integrated farming systems are part of the answer to the world’s impending protein food crisis for both inland and coastal areas (FAO, 2001; Federoff *et al.*, 2010). In 2006, the

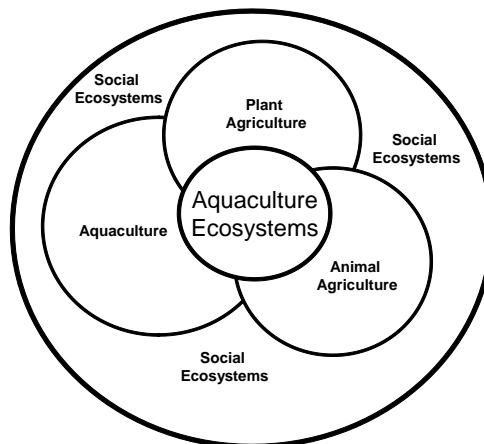


Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) recognized this need and developed guidelines for an ecosystem-based management approach to aquaculture similar to the *Code of Conduct for Responsible Fisheries* (Soto *et al.*, 2008). This ecological approach to aquaculture (EAA) has the objectives of ecological and human well-being and would achieve these ideals via the more effective governance of aquaculture within a hierarchical framework that is scalable from the farm to regional and global levels. Ecological aquaculture is a holistic view of aquaculture development that brings not only the technical aspects of ecosystems design, ecological principles and systems ecology (an integrated framework for planning and design, monitoring, modeling and evaluation) to aquaculture, but also incorporates planning for community development and concerns for the wider social, economic and environmental contexts of aquaculture (Costa-Pierce, 2002, 2008; Yusoff, 2003; Culver and Castle, 2008). Ecological aquaculture farms are “aquaculture ecosystems” (Figure 2). By using an EAA, more sophisticated, environmentally sound designed and integrated aquaculture systems could become more widespread because they better fit the social-ecological context of both rich and poor countries. Ecological aquaculture provides the basis for developing a new social contract for aquaculture because it is inclusive of all producer-stakeholders and decision-makers in a modern, market economy – fisheries, agriculture, ecosystems conservation and restoration (Figure 3).

Aquaculture depends upon resource inputs connected to various food, processing, transportation and other sectors of society. Outputs from aquaculture

FIGURE 2

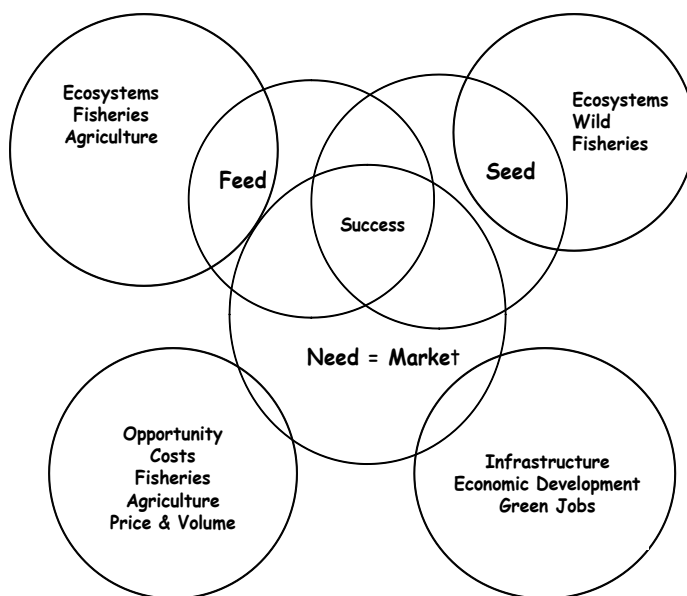
Aquaculture ecosystems mimic the form and functions of natural ecosystems. They are knowledge-based designed farming ecosystems planned as combinations of land and water-based plant, agronomic, algal and animal subunits which are embedded into the larger context of human social systems



Source: Costa-Pierce, 2010.

FIGURE 3

Success of aquaculture developments is not only the alignment of the “seed, feed and need”. Each of these vital aquaculture resources has important interactions with natural ecosystems and the larger society in which they are located and therefore must be planned for in a comprehensive manner, not downgraded, misplaced or as an afterthought in the planning for more sustainable food systems. Comprehensive planning for aquaculture’s economic, employment, ecological and social interactions with opportunity costs in fisheries and agriculture, and goods and services provided by natural ecosystems can ensure not only aquaculture’s success, but also society’s success



Source: Costa-Pierce, 2010.

ecosystems can be valuable, uncontaminated waste waters and fish wastes, which can be important inputs to ecologically designed aquatic and terrestrial ecological farming systems and habitats. In this review, we attempt to summarize data on resource use in aquaculture systems and make comparisons to other terrestrial food production systems, plus examine trends over the past decade since the *FAO Bangkok Declaration and Strategy for Aquaculture Development beyond 2000* and project the trajectories of these to 2050.

Systems ecology of comparable food systems

All modern, large-scale food systems have discernible environmental and social impacts. Even the sustainability of modern, large-scale, organic agriculture has been questioned (Allen *et al.*, 1991; Shreck, Getz and Feenstra, 2006). Fish products are the most widely traded products globally. As such, some important global resources and resource flows have, since the Bangkok Declaration

(NACA/FAO, 2000), been diverted to support its increased growth. A decade ago, Naylor *et al.* (2000) raised the issue of some fed aquaculture systems being a net loss of protein to humanity. Concerns were also raised as to the relative benefits of aquaculture in terms of resource use in comparison to capture fisheries; however, few comprehensive reviews have been conducted to analyze and compare resource use, trends in use, production and energy efficiencies of aquaculture versus other large-scale capture fisheries and terrestrial animal protein production alternatives. Only by comparing efficiencies of terrestrial and aquatic protein production systems can scientists, policy-makers and the public address in a more rigorous manner the available choices for resource use and production systems given the plethora of human needs and user conflicts, and the growing scarcities in water, land, energy and feeds.

No other food animal converts feed to body tissue as efficiently as fish (Smil, 2000). Farmed (fed) fish are inherently more efficient than any other farmed animals, since they are poikilotherms and thus divert less of their ingested food energy to maintain body temperatures. In addition, fish are neutrally buoyant in their environment and thus do not devote as much of ingested food energy to maintain bones/posture against gravity as do land animals. Principally for these reasons fish devote more of their digested food energy to flesh, and thus have much higher meat to bone ratios (and meat “dress out” percentages) in comparison to terrestrial animals. There are also inherent differences in the manner in which stored energy is processed through terrestrial and aquatic ecosystems. Land plants (primary producers) convert more of captured sunlight into plant structures in comparison to aquatic plants, and thus have lower edible percentages. Land plants store most of their energy as starches. Aquatic plants (algae) store oils (lipids) as their primary energy sources. Fish convert lipids much more efficiently than land animals convert starches and other carbohydrates (Cowey, Mackie and Bell, 1985). As a result, fish are the most valuable of any foods for human nutrition, disease prevention and brain development, since they have the highest nutrient density (highest protein and oil contents in their flesh) of all food animals (Smil, 2002).

Mass balances

Comparisons of production efficiencies of aquaculture versus an array of fisheries and terrestrial agriculture systems show that fed aquaculture is an efficient mass producer of animal protein (Table 1). Production efficiencies of edible mass for a variety of aquaculture systems are 2.5–4.5 kg dry feed/kg edible mass, compared with 3.0–17.4 for conventional terrestrial animal production systems. Beef cattle require over 10 kg of feed to add 1 kg of edible weight, whereas catfish use less than 3 kg to add a kg of edible weight. In the worldwide effort to increase food production, aquaculture merits more attention than raising grain-fed cattle (Goodland and Pimental, 2000). Since food conversions to edible mass in aquaculture are lower, aquatic animals inherently produce relatively less pollution than do terrestrial animals, as they

TABLE 1

Production efficiencies of edible proteins from some aquaculture systems compared with some animal agriculture systems

Food system	Feed conversion ratios (kg dry feed/kg wet weight gain +/- standard deviation)	% Edible	Production efficiencies (kg dry feed/kg of edible wet mass)
Tilapia	1.5 (0.2)	60	2.5
Catfish	1.5 (0.2)	60	2.5
Marine shrimp	1.5 (0.5)	56	2.7
Freshwater prawns	2.0 (0.2)	45	4.4
Milk	3.0 (0.0)	100	3.0
Eggs	2.8 (0.2)	90	3.1
Broiler chickens*	2.0 (0.2)	59	3.1
Swine	2.5 (0.5)	45	5.6
Rabbits	3.0 (0.5)	47	6.4
Beef	5.9 (0.5)	49	10.2
Lamb	4.0 (0.5)	23	17.4

* From Verdegem, Bosma and Verreth (2006).

Source: modified from Costa-Pierce (2002) except where indicated.

use nitrogen much more efficiently. Nitrogen use efficiency is 5 percent for beef and 15 percent for pork, while shrimp retain 20 percent and fish 30 percent of ingested nitrogen (Smil, 2002). As a result, aquatic animals release two to three times less nitrogen to the environment in comparison to terrestrial animal food production systems.

Trophic efficiencies

Coastal and oceanic ecosystems have energy transfer efficiencies of 10–15 percent and mean trophic levels of 3.0 to 5.0 (Ryther, 1969). Marine capture fisheries have a mean trophic level of 3.2 (Pauly *et al.*, 1998). Mean trophic levels in aquaculture systems range from 2.3 to 3.3, with highest trophic levels in North America and Europe (Pullin, Froese and Pauly, 2007). Kaushik and Troell (2010) noted an even wider range of fish trophic levels for the species listed in FishBase. Pullin, Froese and Pauly (2007) found most ocean fish consumed by humans have trophic levels ranging from 3.0 to 4.5, which Pauly *et al.* (1998) state are “0 to 1.5 levels above that of lions”. In the wild, however, salmon are not top-level carnivores, as they are consumed by whales, sea lions and other marine predators, and thus cannot be compared to lions. In cage aquaculture systems, salmon eat agricultural and fish meals and oils, so cannot be classified at the same trophic level as wild “carnivores”; rather, such animals in culture are feeding as “farmed omnivores”. Overall, Duarte *et al.* (2009) estimated a mean trophic level of 1.9 for mariculture and 1.0 for agriculture and livestock.

Most recent debates over the efficiencies of fed aquaculture have focused on “fish in/fish out” (FIFO) ratios, but use of single ratios to measure resource efficiencies have been superseded by the more sophisticated development and

use of multiple indicators to compare resource use in aquaculture (Boyd *et al.*, 2007). Since measurement of resource use in aquaculture systems is such an important determinant, it is important to review the evolutionary development of these metrics. Naylor *et al.* (2000) began the FIFO discussion when they reported that for the ten aquaculture species they examined, approximately 1.9 kg of wild fish were required for each 1 kg of farmed production. For flounder, sole, cod, seabass, and tuna, Naylor *et al.* (2000) reported greater than 5 kg of wild fish were required and that “many salmon and shrimp operations use approximately 3 kg of fish for each one produced”. Farmed catfish, milkfish and carp were all found to be “net producers”, since they used less wild fish than was produced by aquaculture. At the time, these data were widely criticized for not accounting for the latest advances in aquaculture feeds, feed management technologies and nutrition science, as the authors chose to calculate FIFO ratios using FCRs for farmed marine fish and farmed salmon of 5:1 and 3:1 (Naylor, *et al.*, 2000) while rapid advances had decreased FCRs to approximately 1.5:1 for farmed marine fish and approximately 1.2:1 for farmed salmon.

Jackson (2009) presented FIFO data for the world’s most commonly farmed species. Jackson (2009) calculated a FIFO ratio for global aquaculture of 0.52, demonstrating that for each tonne of wild fish caught, aquaculture produced 1.92 tonnes of aquaculture products, showing global aquaculture, as currently practiced, is a net benefit to humanity. However, Jackson (2009) calculated a FIFO for salmon of 1.68, the highest for all farmed species, meaning that for every tonne of wild fish used in salmon aquaculture, just 600 kg of farmed salmon were produced, confirming the Naylor *et al.* (2000) concern that such aquaculture systems remain a net loss of protein to society from “FIFO perspective”. Trends in FIFO since 1995, however, all indicate a massive increase in efficiencies of feed use and incorporation of alternative protein meals and oils in fed aquaculture (Table 2). Kaushik and Troell (2010) criticized the

TABLE 2
Trends in “fish in fish” out ratios (FIFO) from 1995 to 2008

	FIFO (1995)	FIFO (2008)
Subsidized aquaculture		
Salmon	7.5	4.9
Trout	6.0	3.4
Eels	5.2	3.5
Miscellaneous marine fish	3.0	2.2
Shrimp	1.9	1.4
Net production aquaculture		
Chinese and Indian major carps		0.2
Milkfish		0.2
Tilapia		0.4
American catfish		0.5
Freshwater prawns		0.6

Source: Tacon and Metian (2008).

calculations of Jackson (2009), recalculating a global FIFO of 0.7 for feed-based aquaculture; but more importantly, they emphasized the need to consider the environmental performances of aquaculture systems more comprehensively and recommended that life cycle and equity approaches (see Ayer *et al.*, 2007) were more appropriate measures of resource use and stewardship in aquaculture. As a complement to life cycle approaches, Boyd *et al.* (2007) gave a more comprehensive set of numerical indicators of resource use in aquaculture.

Efficiencies of resource use in aquaculture

A literature review of resource uses in aquaculture for land, water, energy and seed was conducted, with materials summarized in subsequent Tables. A compilation of trends in each resource that have occurred over the last decade since the Bangkok Declaration with a projection of trends for each to 2050 was accomplished, taken both from literature sources and with inputs from Expert Panel members.

Land use

In the major aquaculture production centers of Asia, serious land constraints for the expansion of aquaculture have occurred over the past decade, especially in China, Indonesia, Bangladesh, Thailand and India (Liao and Chao, 2009). In a few of these areas where capital is available (especially China), intensive aquaculture systems that use less land (and water) have developed using imported feedstuffs for the formulation of pellet feeds for aquaculture. Land use efficiencies for semi-intensive and intensive aquaculture systems are the highest for land-based aquaculture production systems, which produce a tonne of products for as little as 100 m² of land (Table 3). However, these simple calculations do not recognize the concept of the “ecological footprint” of aquaculture or the appropriation of ecosystems goods and services acquired by aquaculture systems in their production (Kautsky *et al.*, 1997; Folke *et al.*, 1998). For example, Tyedmers (2000) measured the area of ecosystem support services for a range of farmed and commercially fished salmon species,

TABLE 3
Efficiencies of land use for aquaculture systems

System type	Description	Production (kg/ha/year)	Efficiency of land use (m ² /tonne)
Extensive	On-farm resources	100–500	20 000–100 000
Extensive	On-farm resources, fertilizers	100–1 000	10 000–100 000
Semi-intensive	Supplemental feeds, static	2 000–8 000	1 250–5 000
Semi-intensive	Supplemental feeds, water exchanges	4 000–20 000	500–2 500
Semi-intensive	Supplemental feeds, water exchanges, night aeration	15 000–35 000	300–700
Intensive	Complete feeds, water exchanges, night aeration	20 000–50 000	200–500
Intensive	Complete feeds, water exchanges, constant aeration	20 000–100 000	100–500

Source: Production figures taken from Verdegem, Bosma and Verreth (2006).

TABLE 4**Area of ecosystem support services needed by salmon fishing and farming systems**

Salmon species, systems	Area use (ha/tonne)
Farmed chinook	16.0
Farmed Atlantic	12.7
Fished chinook	11.0
Fished coho	10.2
Fished sockeye	5.7
Fished chum	5.2
Fished pink	5.0

Source: Tyedmers (2000).

finding that farmed species needed ecosystem support services equivalent to 12.7–16.0 ha/tonne of farmed product, higher than salmon fisheries, which appropriated 5.0–11.0 (Table 4).

Trends in land use are:

Trends in the last decade:

- Ponds have high land use in comparison to terrestrial agricultural protein production systems.
- Rice fields are increasingly being converted into fish ponds in many countries (Hambrey, Edwards and Belton, 2008).
- Application of the use of “footprints” to quantify areas of ecosystem support services required per tonne of aquaculture production.

Projected Trends to 2050:

- Ponds taken over by urbanization.
- Cage systems proliferating with user conflicts driving the development and use of submerged systems.
- More widespread use of cages in small waterbodies, reservoirs and coastal open waters, but submerged systems more common in marine areas.
- Intensive recirculating systems are more efficient uses of land (ha/tonne aquaculture production) than terrestrial animal production systems but remain uneconomic in most areas of Asia in comparison to other production systems.
- More widespread use of integrated aquaculture into landscape-scale systems of mixed aquaculture/land uses.
- Greater use of land/water use planning to address growing land/water user conflicts.

Water use

A compilation of various studies on water use in aquaculture and animal production systems is shown in Table 5. Intensive, recirculating aquaculture systems are the most efficient water use systems. Extensive aquaculture pond systems and intensive, terrestrial animal production systems are the least

TABLE 5
Estimated consumptive water usages in aquaculture and terrestrial agriculture protein food

Systems	Estimated freshwater use (liters/kg product)	References	Comments
LOW USE: Ave. use less than 3 000 liters/kg product			
Seawater farming (halophytes, marine fish, shellfish, seaweeds, euryhaline fish such as tilapia)	0–100	Hodges <i>et al.</i> (1993), Federoff, <i>et al.</i> (2010), www.seawaterfoundation.org	Freshwater use is for makeup waters to replace evaporation in land-based farming systems
Small farm pig production	0–100	Zimmer and Renault (undated)	In China, about 80 % of pig meat production (estimated 454 million heads) is of this type
Vegetables (cabbages, eggplants, onions)	100–200	Smil (2008)	
Lemons, limes, oranges, grapefruit, bananas, apples, pineapples, grapes	286–499	Barthélemy, Renault and Wallender (1993)	In California, USA
Recirculating aquaculture systems	500–1 400	Verdegem, Bosma and Verreth (2006)	Intensive African catfish, eel and turbot fed complete feeds
Wheat, millet, rye	1 159	Barthélemy, Renault and Wallender (1993)	In California, USA
Wheat	1 300	Smil (2008)	
Sugar	1 929	Barthélemy, Renault and Wallender (1993)	In California, USA
Soybeans	2 000	USDA (1998)	
Legumes (peas, beans)	2 000–4 000	Smil (2008)	
Rice	2 300	Smil (2008)	
Egg production	2 700	Verdegem, Bosma and Verreth (2006)	
Milk production	2 700	Verdegem, Bosma and Verreth (2006)	Temperate dairy farm
Freshwater fish production	2 700	Verdegem, Bosma and Verreth (2006)	Intensively mixed pond with production of 100 tonnes/ha/year
Tilapia	2 800	Brummett (1997)	

Production systems ¹

HIGH USE: Ave. use 3 000–10 000 liters/kg product			
Some legumes	>3 000	Smil (2008)	
Sunflowers	3 283	Barthélemy, Renault and Wallender (1993)	In Egypt
Catfish	3 350 (with reuse for irrigation)	Brummett (1997)	
Catfish	4 000–16 000 (lowest for undrained embankment ponds, highest for drained watershed ponds)	Boyd (2005)	Eliminating well water as consumptive use would decrease water use in embankment ponds to 2 600–3 200 l
Broiler chickens	3 500	Pimentel and Pimentel (2003)	

TABLE 5 (Continued)

HIGH USE: Ave. use 3 000–10 000 liters/kg product			
Rapeseed and mustard seed oils	3 500	Barthélemy, Renault and Wallender (1993)	In California, USA
Chicken	4 000	Smil (2008)	
Pigs (farrow-finish operation)	4 700	Verdegem, Bosma and Verreth (2006)	
Fish in freshwater ponds	5 200	Verdegem and Bosma (2009)	If infiltration, drainage and recharge are considered green water
Soybean oil	5 405	Barthélemy, Renault and Wallender (1993)	In Egypt
Coconut oil, cottonseed oil, palm oil, palm kernel oil, sesame seed oil	5 500	Zimmer and Renault (undated)	In Malaysia, Indonesia
Pork	6 000	Pimentel and Pimentel (2003)	
Channel catfish	6 300 industry wide	Brummett (1997)	
Pangasiid catfish	6 400 ave. industry wide	Phan <i>et al.</i> (2009)	In Viet Nam
Fish in freshwater ponds	4 700–7 800	Verdegem, Bosma and Verreth (2006)	Production of 10–20 tonnes/ha/year with nighttime aeration
Sunflower seed oil	7 550	Barthélemy, Renault and Wallender (1993)	In California, USA
Groundnut oil	8 713	Barthélemy, Renault and Wallender (1993)	In California, USA
Pork	10 000	Smil (2008)	
EXTREME USE: Ave. use >10 000 liters/kg product			
Shrimp farming in ponds	11 000–43 000	Beveridge, Phillips and Clarke (1991)	
Olive oil	11 350	Barthélemy, Renault and Wallender (1993)	In Tunisia
Fish culture	11 500	Verdegem, Bosma and Verreth (2006)	Fed freshwater species
Beef	15 000–43 000	Smil (2008); Pimentel and Pimentel (2003)	
Butter	18 000	Barthélemy, Renault and Wallender (1993)	In California, USA
Trout (90% recycling)	25 000 (252 000 withdrawal)	Brummett (1997)	
Boneless beef	30 000	Smil (2008)	
Fish in freshwater ponds	30 100	Verdegem, Bosma and Verreth (2006)	Production of 30 tonnes/ha/year with 20% water exchange
Extensive fish culture	45 000	Verdegem, Bosma and Verreth (2006)	No feed
Sheep	51 000	Pimentel and Pimentel (2003)	
Pangasiid catfish	up to 59 700 (700 to 59 700)	Phan <i>et al.</i> (2009)	In Viet Nam
Trout (75% recycling)	63 000 (252 000 withdrawal)	Brummett (1997)	

¹ Consumptive water use in aquaculture remains a controversial measure. J.A. Hargreaves (personal communication, 2011) noted that Boyd (2005) defined, then measured water use in aquaculture, but that his definition included groundwater use as consumptive use, which contradicts the definitions used by hydrologists and agricultural scientists (Gleick, 2003; Falkenmark and Lannerstad, 2005; Lamm, 2008).

efficient. Water use in aquaculture can be extreme – as high as 45 m³/kg of fish production. The potential for increased water use efficiencies in aquaculture is higher than in terrestrial systems. Globally, about 1.2 m³ (or 1 200 liters) of water is needed to produce 1 kg of grain used in animal feed (Verdegem, Bosma and Verreth, 2006). A kg of tilapia can be produced with no consumptive freshwater use (e.g. in cages, seawater farming systems) or using as little as 50 liters of freshwater (Rothbard and Peretz, 2002). Seawater aquaculture systems (mariculture) can use brackishwaters unsuitable for agriculture; plus, integrated, land-based saltwater farming is possible (Fedoroff *et al.*, 2010).

Water use is connected to changing land use, and conflicts between these have reached a crisis point in some of the major aquaculture farming regions of the world, such as Bangladesh. Fish and fisheries are very important in Bangladesh, where millions of people are directly and indirectly involved. Aquaculture, which developed only recently (1980s) in Bangladesh, now contributes around 40 percent of total fish production of the country (FAO, 2009). Bangladesh is a nation of rivers that originate in the Himalayas. It is home to a huge hydrological system that connects the world's highest mountains to the Bay of Bengal. Upstream dams in India across South Asia's major rivers (e.g. the Ganga, Tista) have caused serious water problems in southern Bangladesh, which is a major aquaculture production zone. As a result, important tributaries are drying, reducing both capture fisheries and aquaculture production. Fish breeding, nursery and feeding areas have been degraded due to heavy siltation and less water in the rivers.

Coastal Bangladesh has rapidly become saline due to the decreased flows of freshwaters and intrusions of saline waters from the Bay of Bengal, which has disrupted both rice and shrimp farming in the region.

Trends in water use are:

Trends in the last decade:

- High water use in ponds in comparison to terrestrial agricultural protein production systems.
- Severe water competition growing with alternative users.
- Massive damming and urbanization in Asia diverting water to coastal cities and agriculture.

Projected Trends to 2050:

- Upstream dams cut off downstream users.
- Freshwater use conflicts and droughts increase in aquaculture production zones, closing many pond areas.
- More rapid development of cage systems in open waters.
- Rapid decrease in the costs and increased efficiencies of intensive, recirculating systems that use water more efficiently than ponds and terrestrial animal production systems.

- Multiple uses of water in landscape-scale systems of mixed reservoir production with downstream aquaculture/agriculture.
- Changes to traditional rice/fish systems in Asia, with large-scale land modification, addition and replacement of rice with high-value species (prawns) in Bangladesh, Viet Nam and China.
- Development of seawater farming systems in arid areas.
- Development of low-energy membranes with wind turbines breaking the 2 kW/h/m³ barrier which accelerates use of seawater for freshwater aquaculture.

Energy use

A compilation of various studies on energy use in aquaculture and animal production systems is shown in Table 6. Seaweed and extensive pond aquaculture of omnivores are comparable to vegetable farming, while mussel aquaculture is comparable to sheep and rangeland beef farming. Catfish farming is similar to poultry and swine production. Cage aquaculture of salmonids and marine fish is comparable to intensive capture fisheries.

Energy comparisons between systems have become part of more detailed analyses of life cycles (Papathyphon *et al.*, 2004; Ayer and Tyedmers, 2008). Comparisons of these with terrestrial farming show clearly the huge production benefits of intensive aquaculture, albeit at a much higher energy cost, contained mostly in feed (Ayer and Tyedmers, 2008, Table 7). Over the coming decades, increasing global energy, processing, shipping/transportation costs of both products and feeds are predicted (FAO, 2008a; Tacon and Metian, 2008).

Trends in energy use are:

Trends in the last decade:

- Globalization and intensification of food production increases energy density and use in fed aquaculture in comparison to fishing and terrestrial agricultural protein production systems.

Projected Trends to 2050:

- Recirculating systems are energy intensive compared to other systems and have large carbon footprint.
- Life Cycle Assessments show advantages/disadvantages of aquaculture.
- Large-scale development and use of cost-effective renewable energy systems make intensive recirculating systems more widespread and accessible.

Feed use

Aquaculture uses most of the world's fishmeal (68 percent) and fish oil (88 percent) with the balance used by intensive livestock agriculture and for pet foods (Tacon, 2005; Tacon, Hasan and Subasinghe, 2006; Tacon and Metian, 2008). Salmon, trout and shrimp aquaculture, which account for less than 10 percent of world aquaculture production use an estimated 26 percent of the world's

TABLE 6
Ranking of fossil fuel protein production efficiencies for various aquatic and terrestrial food production systems

Food production system	Fossil fuel energy input/protein output (kcal/kcal)
LOW ENERGY USE (ave. use less than 20 kcal)	
North Atlantic herring fisheries	2–3
Seaweed aquaculture, West Indies and elsewhere	1 (range 5–7)
Carp aquaculture, Asian ponds	1–9
Vegetable row crops	2–4
North Pacific salmon fisheries	7–14
Atlantic salmon ranching	7–33
Tilapia aquaculture, Indonesian ponds	8
Trout cage aquaculture, Finland & Ireland	8–24
Rangeland beef	10
Sheep agriculture	10
North Atlantic cod fisheries	10–12
Mussel aquaculture, European longlines	10–12
USA Dairy	14
Tilapia aquaculture, Africa semi-intensive	18
HIGH ENERGY USE (ave. use 20–50 kcal)	
Cod capture fisheries	20
Rainbow trout raised in cages	24
USA eggs	26
Atlantic salmon capture fisheries	29
Pacific salmon fisheries	up to 30 (range 18–30)
Broiler chickens	up to 34 (range 22–34)
American catfish raised in ponds	up to 34 (range 25–34)
Swine	35
Shrimp aquaculture, Ecuador ponds	40
Atlantic salmon cage aquaculture, Canada & Sweden	up to 50 (range 40–50)
EXTREME USE (ave. use greater than 50 kcal)	
North Atlantic flatfish fisheries	53
Seabass cage aquaculture, Thailand	67
Shrimp aquaculture, Thailand ponds	70
Feedlot beef	up to 78 (range 20–78)
Oyster aquaculture, intensive tanks, USA	136
North Atlantic lobster capture fisheries	up to 192 (range 38–59)
Shrimp capture fisheries	up to 198 (range 17–53)

Source: summarized from Costa-Pierce (2002) and Troell et al. (2004); where multiple studies exist, they are both listed.

fishmeal, but 74 percent of the fish oil (Tacon and Metian, 2008). However, Tacon and Metian (2008) predict that fishmeal and oil use in aquaculture will decrease while aquaculture production grows significantly (Figure 1), and that fishmeal/oil will increasingly be diverted from uses as bulk products to high-priced, specialty feed ingredients.

TABLE 7

Total energy use efficiencies of agriculture versus salmon farming systems. To obtain salmon production, data in Table 1 in Ayer and Tyedmers (2008) was used and a cage depth of 5 m

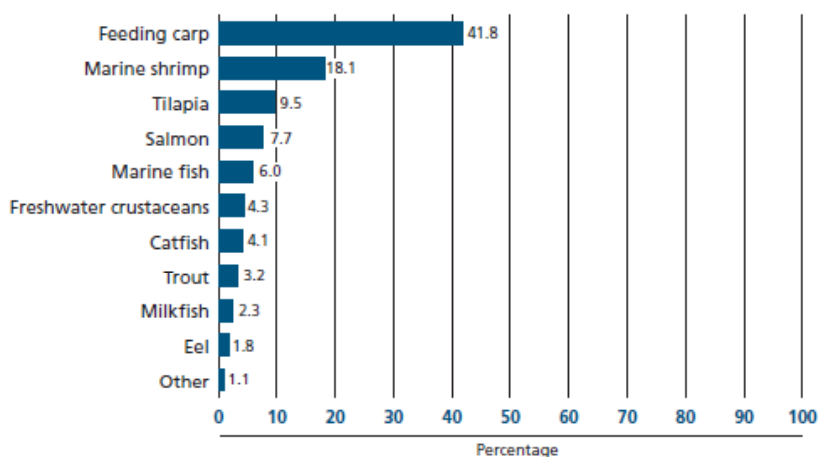
Food system	Production (tonnes/ha)	MJ/tonne	References
Sugar beets	57.9	550	Elferink, Nonhebel and Moll (2008)
Potatoes	47.0	940	Elferink, Nonhebel and Moll (2008)
Soybeans	2.5	2 950	Elferink, Nonhebel and Moll (2008)
Wheat	8.2	3 100	Elferink, Nonhebel and Moll (2008)
Canada salmon net-pen, water-based	1 000	26 900	Ayer and Tyedmers (2008)
Canada salmon bag system, water-based	1 733	37 300	Ayer and Tyedmers (2008)
Canada salmon flow-through, land based	2 138	132 000	Ayer and Tyedmers (2008)
Canada salmon recirculating, land-based	2 406	233 000	Ayer and Tyedmers (2008)

The major development in feed use in aquaculture over the past decade has been the rapid increase in the global trade of feedstuffs and feeds for fed aquaculture systems in Asia which has allowed the widespread use of formulated feeds. Tacon and Metian (2008) estimated that in 2005 about 45 percent of world aquaculture production (about 63 million tonnes, including aquatic plants) was estimated to be dependent on the direct use of feed, either as a single feed ingredient, farm-made aquafeed or as industrially manufactured compound aquafeeds. A striking increase in the use of formulated feeds for the intensification of herbivorous and omnivorous fish culture in Asia, especially for carps in China, India and Bangladesh and for catfish in Viet Nam has occurred since the Bangkok Declaration. An estimated 23 million tonnes of aquafeed was produced in 2005, and about 42 percent was consumed by carps (Figure 4). However, it has to be noted that the use of fishmeal for carp feed is only about 13–14 percent of total fishmeal use for aquaculture, while the amount of fishmeal used for salmonids, marine fish and marine shrimp is 18, 18 and 22 percent, respectively.

Research on the use of agricultural meals and oils to replace use of ocean resources (especially the functional components of fishmeals/oils needed for fish nutrition) are a major subject of aquaculture research and development (Watanabe, 2002; Opstvedt *et al.*, 2003). Turchini, Torstensen and Ng (2009) reported that for all of the major aquaculture fish species, 60–75 percent of dietary fish oil can be substituted with alternative lipid sources without significantly affecting growth performance, feed efficiency and feed intake. Oo *et al.* (2007) found that palm oil could replace fish oil in rainbow trout diets and reduce the dioxin contents in fish.

Current projections forecast an expansion of agricultural and other terrestrial sources of feed proteins and oils in aquaculture, and these alternatives are

FIGURE 4
The major global consumers of aquafeeds are herbivorous and omnivorous fish and shrimp



Source: Tacon and Nates (2007).

developing rapidly. Terrestrial proteins and oils from soybeans, sunflowers, lupins and rendered livestock are available at volumes larger than the quantity of global fishmeal. Soybeans have high protein content of ~28 percent, peas have ~22 percent, and these have good amino acid profiles. Other abundant cereals have protein contents of only 12–15 percent. However, soybean meal processing can create protein concentrates with protein levels of >50 percent (Bell and Waagbo, 2008). Vegetable oils have very low eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) levels. However, substitution of plant oils upwards of 50 percent of added dietary oil has not resulted in growth reductions or increased mortalities in fish such as salmon and trout. Terrestrial animal by-products from the rendering industry are the largest supply of high-quality feed-grade animal protein and lipid for animal feeds (Tacon and Nates, 2007).

The massive use of plant resources in feeds for meat production in developed countries has been recently questioned, considering food deficits of some countries and regions and the global food availability balance (Agrimonde, 2009). According to this study, attending for predicted population increments in food-deficit countries in the next decades would include the access to some near food-grade raw materials currently used for animal feeds. Thus, future aquafeeds could largely depend upon lower grade raw materials (including those possibly recovered from crop wastages) that may be further improved by processing and biotechnological transformation to fit as consistent nutrient sources for farmed species. This variety of available raw materials with different qualities and costs would further require strategic diversification in feed formulation and processing strategies to allow manufacture flexibility according to availability and cost-benefit relationship.

If agricultural sources of meals and oils are the future of fed aquaculture, there will be a need for a new global dialogue on the impacts of fed aquaculture as a driver of agriculture production, especially so for soybeans. Increased aquaculture consumption of the world's grains and oils raises concern over the spread of unsustainable agriculture practices. Brazil has been targeted as one of the world's major soybean suppliers. Costa *et al.* (2007) have demonstrated that soybean farms are causing reduced rainfall in the Amazonian rainforest. About one-seventh of the Brazilian rainforest has been cut for agriculture, about 15 percent of which is soybeans. Soybeans, which are light in color, reflect more solar radiation, heating the surface of the land less and reducing the amount of warm air convected from the ground. Fewer clouds form as a result, and less precipitation falls. In soybean areas, there was 16 percent less rainfall compared to a 4 percent decrease in rainfall in land areas cleared for pasture.

Trends in feed use are:

Trends in the last decade:

- Overuse of marine meals/oils, threatening sustainability of pelagic fish stocks.
- High feed costs.
- Fish feed ingredients imported, and there is a crisis in feed qualities; meat-bone meal also imported but quality is not assured.
- Social equity/poverty concerns with use of pelagics as feeds rather than as direct human foods.
- Polychlorinated biphenyl (PCB) and mercury contamination of fishmeals/oils.

Projected Trends to 2050:

- Increased use of imported fishmeals/oils in formulated feeds for traditional carp and imported tilapia species in Asia (especially in China), decreasing FCR.
- Increased use of wet feeds (cakes, wastes from poultry processing plants) and chicken manures in South Asia fish culture with high FCR (>3.0), resulting in deterioration of water quality.
- Decreased use of marine meals/oils in intensive cage/tank systems and improvement in FCRs.
- Replacement of marine meals/oils by agricultural sources and by algal/bacterial/fungal bioreactors, but new issues arising about aquaculture leading to deforestation.
- Use of biotechnology to elongate/upgrade essential fatty acids.
- Cleansing of oils by high technology.

Seed

A major FAO review of freshwater seed sources for aquaculture which included 21 country case studies was completed recently by Bondad-Reantaso (2007). Studies indicated that seed resources were an essential and profitable phase of

aquaculture production, and that efficient use of seed resources is necessary to guarantee optimum production. Studies identified challenges concerning water allocation and land use conflicts for seed culture production in all countries. The study recommended a shift from high-water-use, land-based hatchery systems to water-saving and water-productivity-enhancing technologies such as integrating seed production with agriculture and optimizing the use of irrigated agricultural land, and the use of cages and *hapas* for fry to fingerling rearing, especially where large numbers of perennial waterbodies exist. Such integrations enhance the productivity of reservoirs and irrigation dams and enable landless households to participate in aquaculture.

Seed quality is related to the quality of the broodstock used, genetic quality and good hatchery/nursery management. Broodstock management and seed quality will be a key issue in meeting projected fingerling requirements to 2020 (Bondad-Reantaso, 2007). Approaches to genetic improvement using selective breeding, use of genetic markers, sex control techniques, chromosome set manipulation, crossbreeding and transgenesis need to be integrated during the domestication and translocation of aquaculture stocks. Seed certification and accreditation of hatchery practices are needed worldwide. Certification is a quality assurance system with certain minimum predetermined quality standards and criteria (e.g. genetic purity, appropriate husbandry, high grow-out performance, pathogen-free status). Seed certification is part of a wider programme on genetics and breeding, biodiversity conservation and international trade. In many Asian countries, seed is produced in hundreds of small hatcheries where genetic erosion is a serious concern. For example, around 99 percent of freshwater seed available in Bangladesh is produced in about 900 public and private hatcheries where the quality of seed has seriously deteriorated due to genetic erosion of broodstock.

Trends in seed use are:

Trends in the last decade:

- Inadequate and unreliable supply of quality seed.
- Poor genetic quality of seed.
- Basic production from regional hatcheries – the human infrastructure, financial and business/marketing support, and policy and legal frameworks are not in place in many nations.
- Impacts of uncontrolled releases of cultured seed stocks.

Projected Trends to 2050:

- Rapid expansion of export-oriented international seed trade, especially of high-value species.
- Increasing need to introduce quality assurance measures beyond simple official zoosanitary certificates.
- Regional hatchery infrastructure taking shape in many nations.

Non-fed aquaculture

Concerns and constraints regarding the expansion of global aquaculture are much different for fed and non-fed aquaculture. Non-fed, herbivorous fish capture-based aquaculture in Asian reservoirs remains a major source of production, but has not expanded (Lovatelli and Holthus, 2008). In Africa, aquaculture of herbivorous fish in reservoirs remains a priority but is still poorly developed, largely due to inadequate hatchery capacity and training, despite including countries having some of the highest reservoir densities in the world (Sri Lanka has the highest density at 230 ha/100 km², while Zimbabwe has 139) (Petr, 2005). Seaweed aquaculture is one of the world's largest marine production systems, with plant production in 2004 reaching an estimated 13.9 million tonnes, of which 99.8 percent originated in the Asia-Pacific region, 10.7 million tonnes from China. Japanese kelp (*Laminaria japonica* – 4.5 million tonnes) was the most commonly produced species, followed by wakame (*Undaria pinnatifida* – 2.5 million tonnes) and nori (*Porphyra tenera* – 1.3 million tonnes) (FAO, 2008b). Production of aquatic plants has increased rapidly from the 2002 total of 11.6 million tonnes, mainly due to large production increases in China. The greatest threats to aquatic plant production in Asia are water pollution, biofouling and the urbanization of coastal ocean areas.

For non-fed, shellfish aquaculture, there has been a convergence over the past ten years or so around the notion that user conflicts in shellfish aquaculture can be solved not only through technological advances, but also by a growing global science/non-governmental organization (NGO) consensus that shellfish aquaculture can “fit in” in an environmentally and socially responsible manner, and into many coastal environments, many of which are already crowded with existing users (Costa-Pierce, 2008). Included in this “evolution” of shellfish aquaculture are:

- Development of submerged technologies for shellfish aquaculture such as longlines (Langan and Horton, 2003), modified rack and bag shellfish gear (Rheault and Rice, 1995) and upwellers for nursery stages of shellfish, some of which are placed unobtrusively under floating docks at marinas (Flimlin, 2002).
- Scientific findings and reviews demonstrating the environmental benefits of shellfish aquaculture in providing vital ecosystem and social services (National Research Council, 2010) such as nutrient removal (Haamer, 1996; Lindahl *et al.*, 2005) and habitat enhancement (DeAlteris, Kilpatrick and Rheault, 2004; National Research Council, 2010).
- Research on natural and social carrying capacities for shellfish aquaculture and on sophisticated, collaborative work group processes (McKinsey *et al.*, 2006; Byron *et al.*, 2011).
- Development and wide use by industry of best (and better) management practices (BMPs) (National Research Council, 2010).

- Diversification of traditional wild-harvest fishing/shellfishing families into shellfish aquaculture as part-time enterprises, breaking down barriers between fishing/aquaculture user communities.
- Publication of global comparisons with fed aquaculture indicating a strong movement in shellfish aquaculture globally towards an adoption of ecological approaches to aquaculture at all levels of society (Costa-Pierce, 2008).

Major constraints to shellfish culture are the growing occurrences of red tides causing paralytic shellfish poisoning and the proliferation of human bacterial and viral diseases.

Major trends potentially affecting resource allocation and uses

“As population growth, urbanization, and climate change have affected all industrial inputs and outputs, humanity entered, for all food producing industries, the sustainability transition at the turn of the 21st century.” (Brown, 2009).

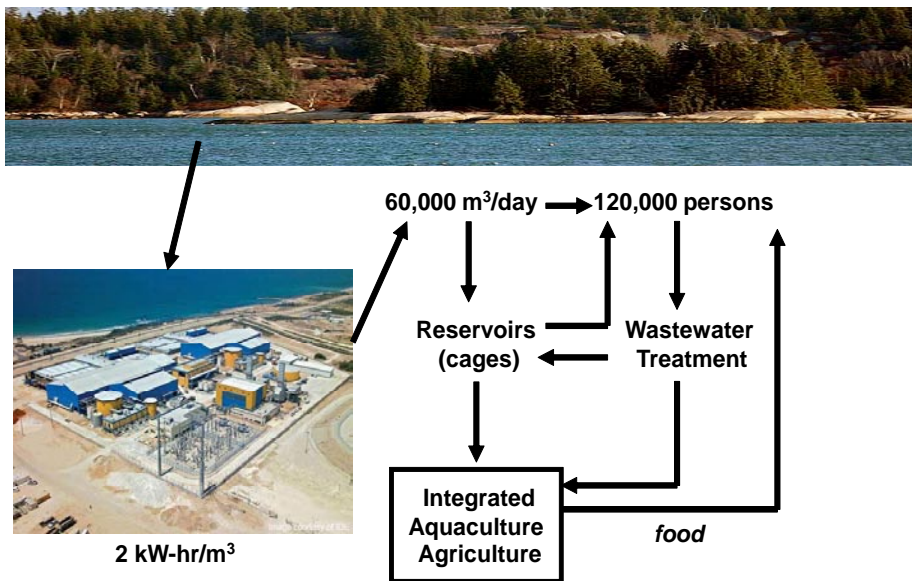
The three major trends occurring in the last decade that will affect decision-making as to resource use and allocation in aquaculture are: (i) energy use in transportation affecting the globalization/localization of aquaculture feeds and products; (ii) capital investments in alternative energy; and (iii) a global strategy for aquaculture to deliver massive amounts of aquatic proteins to the world’s poor.

Increasing seafood imports remains a viable option for the rich countries such as Japan, the United States of America and the Member States of the European Union, but it is questionable if this level of globalization is sustainable and will continue, especially as the era of “peak oil” arrives and fuel prices continue to rise. The UK Energy Research Centre (UKERC, 2009) reports that peak oil may be reached by 2030 and that humanity may have already consumed 1 228 of the estimated 2 000 billion barrels of the “ultimate recoverable resource”. Local seafood production will spread rapidly as the cost and availability of transportation fuels from oil increase. Rapid developments of alternative energy and water treatment systems (desalinization) offer new opportunities for large-scale integrated food production in the coastal zone (Figure 5).

Siting of intensive industrial aquaculture facilities, especially siting of cages in enclosed seas such as the Mediterranean Sea, is a very controversial topic, especially so when it is now estimated that cage aquaculture facilities contribute ~7 percent of total nitrogen and ~10 percent of total phosphorous discharges (Pitta *et al.*, 1999). Inappropriate siting of cages has been blamed for the destruction of nearshore and benthic aquatic ecosystems (Gowen and Bradbury, 1987). However, Mirto *et al.* (2009) found that if seabass/seabream cages were sited above seagrass (*Posidonia oceanica*) meadows, the seagrasses responded

FIGURE 5

Coastal ecological aquaculture systems of the future will merge energy, desalination and wastewater treatment with integrated aquaculture-agriculture systems to deliver renewable sources of energy, food and water. This pictorial diagram is an ecological design which connects three coastal 3 MW electric-generating windmills to a coastal desalination plant using low energy, reverse osmosis membranes (the Ashekon plant in Israel is pictured) to produce freshwater that can be used for: a) human direct consumption (120000 persons), and/or b) food production in integrated reservoir/aquaculture-farming systems



Source: Tacon and Nates (2007).

positively to aquaculture discharges and that there were no impacts on benthic biodiversity. These findings raise the possibility that seagrass meadows can be created and enhanced by ecological engineering of a systems approach and evolving a non-toxic, cage ecological aquaculture model for fish production and environmental improvement in this region. There are well-developed examples of aquaculture ecosystems, both land and water-based, mostly in Asia (Costa-Pierce, 2008; Hambrey, Edwards and Belton, 2008; Edwards, 2009). In the West, there are few commercial aquaculture ecosystems, with most being small-scale, research and development operations; however, there are advanced freshwater aquaculture ecosystems that combine aquaculture units (ponds/tanks), aquaponics for food and fodder with wetlands, and aquaculture ecosystems that incorporate advances in waste treatment and solar energy, and others that are landscape ecological models that have a tight integration between aquaculture and agriculture (Rakocy, 2002; Costa-Pierce and Desbonnet, 2005; Costa-Pierce, 2008). A wide array of technologies and organisms can be used to not only remediate nutrient discharges (especially nitrogenous compounds)

TABLE 8
Different organisms/technologies used in biological management of nitrogenous compounds to improve water quality in aquaculture systems

Organisms/technologies	% reduction/uptake
Bacteria – <i>Nitrosomonas</i> and <i>Bacillus</i>	96% TAN*
Fungus – <i>Aspergillus niger</i>	25 mg TAN/liter
Fungus – <i>Penicillium</i>	0.72 mg TAN/liter
Macrophyte – <i>Elodea densa</i>	0.2 mg NH ₄ -N/liter; 0.4 mg NO ₂ -N/liter
Biofilter	3.46 g TAN/m ³ /d; 0.77 g NO ₂ /m ³ /d
Trickling filter	0.24–0.55 g TAN/m ² /d 0.64 g TAN/m ² /d
Microbead filter	0.450.60 g TAN/m ² /d 0.30 g TAN/m ² /d
Fluidized bed reactor	0.24 g N/m ² /d
Seaweed – <i>Ulva lactuca</i>	49-56% mean NH ₃ -N
Seaweed – <i>Ulva pertusa</i>	0.45 g N/m ² /d
Periphyton – cyanobacteria	91% TAN/liter; 91% NO ₂ -N/liter
Periphyton – diatoms	62% TAN/liter; 82% NO ₂ -N/liter
Periphyton	0.56 mg TAN/liter
AquaMats®	0.22 g ammonia/m ² /d
Biofilms	0.42 µg ammonia/liter
Immobilized nitrifying bacteria	4.2–6.7 mg TAN/liter/d

* TAN = Total ammonia nitrogen.

Source: Yusoff *et al.* (2010). References to the many individual studies that are summarized here can be found in the paper.

from aquaculture but also produce additional, highly valuable aquatic crops for human consumption or for environmental and agricultural improvement (Table 8). In Israel, highly efficient, landscape-sized integrations of reservoirs with aquaculture and agriculture have been developed (Hepher, 1985; Mires, 2009), as well as highly productive, land-based aquaculture ecosystems for marine species (Neori, Shpigel and Ben-Ezra, 2000). Intensive, integrated coastal farming systems are common in many areas of China where the two main forms of marine integrated systems are seaweed aquaculture integrated with fish cages and suspended shellfish aquaculture (Troell *et al.*, 2009). In China, the polyculture of shrimp with mussels, and clams plus crabs is also popular, with shrimp yields of approximately 300–600 kg/ha/year (Nunes *et al.*, 2003), which, if properly managed, could be a model for ecological intensification worldwide (Nunes *et al.*, 2011).

A global strategy for aquaculture to assist in delivering more benefits to the world's poor could include:

1. Allocating more feed fish for poverty alleviation and human needs worldwide, thus allocating less for fed aquaculture so as to: (a) increase the ecosystem resilience of the Humboldt ecosystem, and (b) relieve the increasing overdependence of aquaculture countries such as Thailand (shrimp) and

Norway (salmon) on this southeastern Pacific Ocean marine ecosystem. Alder *et al.* (2008) estimated that about 36 percent of the world's fisheries catch (30 million tonnes) is processed into fishmeal and oil, mostly to feed farmed fish, chickens and pigs. Jacquet *et al.* (2009) report that Peru exports about half of the world's fishmeal from its catch of 5–10 million tonnes/year of anchovies while half of its population of 15 million live in poverty and 25 percent of its infants are malnourished. A campaign launched in 2006 combining scientists, chefs and politicians to demonstrate that anchovies are more valuable to the Peruvian people and its economy as direct foods has resulted in a 46 percent increase in demand for fresh anchovies and 85 percent increase in canned product. One tonne of fillets has sold for five times the price of 1 tonne of meal and requires half the fish (3 tonnes for 1 tonne of fillets vs 6 tonnes for 1 tonne of meal). Peru has decided to dedicate 30 percent of its annual food security budget (approximately USD80 million) for programmes to supply anchovies to its people. Higher prices for fish used as direct human foods for food security will limit processing of fish to meals for terrestrial animal and aquaculture feeds, thereby decreasing the supply of fishmeal and oils for global aquaculture trade and development but meeting the Millennium Development Goals of eliminating everywhere extreme hunger and starvation.

2. Accelerating research into elucidating the functional feed ingredients in fish diets that are showing the potential to eliminate the needs for fishmeal and oils in aquaculture. Skretting Aquaculture Research Centre (2009) reported on research on “functional ingredients” that are contained in fishmeals and oils which contribute to efficient feed conversions and high growth rates, fish health and welfare. Initial research focused on beta-glucans that stimulate the immune system of fish and protect against the effects of bacterial furunculosis while also allowing reductions in fishmeal contents in diets to 25 percent. Additional research in 2008 with phospholipids in meals, triglycerides in fish oil and antioxidants have resulted in excellent fish performances from feeds with almost no marine fishmeal and oil. Current research is exploring the extraction of functional ingredients from other non-marine by-products.

Developing alternative ecological aquaculture models that accelerate the movement towards the use of agricultural, algal, bacterial, yeasts meals and oils.

The globalization of seafood trade has meant less dependence on local natural and social ecosystems, and has resulted in some virulent opposition to aquaculture development, especially as industrial aquaculture has removed the local sources of production and markets, and jobs have been externalized. One major consequence of this globalization has been the increased dependence of industrial, “fed” aquaculture on the southeastern Pacific Ocean marine ecosystem for fishmeals and oils. The global implications for the Humboldt ecosystem, for local poverty, and the scoping of this unsustainable situation

to the entire global protein food infrastructure are profound and are still largely unrealized.

The Bangkok Declaration expressed the need to develop resource-efficient farming systems which make efficient use of water, land, seed and feed inputs by exploring the potential for commercial use of species feeding low in the food chain. Although significant resource competition exists, significant technological advancements in aquaculture over the past decade have occurred to make production systems less consumptive of land, water and energy, to the point where aquaculture resource use, overall, is comparable to poultry production. However, there are serious questions about feed resources over the next decade. The potential is limited for direct or on-farm integration to satisfy national food security due to the limited on-farm resource bases, especially in Africa. To make a more significant contribution by increasing production, there is a need to use off-farm inputs, as has occurred most dramatically in Asia. Currently, about 40 percent of aquaculture depends on formulated feeds: 100 percent of salmon, 83 percent of shrimp, 38 percent of carp (Tacon and Metian, 2008). An estimated 72 percent of all use of global aquafeeds is by low-trophic-level herbivorous and omnivorous aquatic organisms (carps, tilapias, milkfish and shrimp) (Figure 4). Trophic-level positioning for aquaculture species that is contained in the “FishBase” database for wild species is thereby less useful as an indicator of “sustainability”.

The major species being fed in Asia are “herbivores/omnivores” such as tilapia, *labeo rohro*, grass carp, common carp, and striped catfish, each of which dominates in various countries. Where aquaculture is growing rapidly (e.g. China, Viet Nam, Bangladesh and India) many finfish aquaculture systems are increasingly being fed on lower quality “cakes”, which are mixtures of local brans, oil cakes and manure from intensive terrestrial animal feedlots. Discharges from these systems are causing water quality problems. Movement of these aquaculture production centers towards the use of high-quality complete feeds could exert major pressure on global (and regional) marine and agricultural meals/oil resources. Pangasiid catfish development in ponds in the Mekong Delta of Viet Nam by 2007 was estimated at 683 000 tonnes, 97 percent fed by commercial feeds from 37 feed companies (Phan *et al.*, 2009). Plans are to expand this production to 1.5 million tonnes over the next few years, causing concerns not only over feed but on water use as well.

Conclusions

The next 20 years will see an increase in the efficient use of land, water, food, seed and energy through intensification and widespread adoption of integrated agriculture-aquaculture farming ecosystems approaches. However, this will not be enough to increase aquaculture production, as these will improve only the efficiency of use, and increase aquaculture yields per unit of

inputs. An exponentially growing population will require aquaculture to expand rapidly into land and water areas that are currently held as common pool resources (“commons”). This raises issues of access to and management of common pool resources, which could result in conflicts with existing users and potentially acute social, political and economic problems. Nobel Laureate Elinor Ostrom provides important insights for the future expansion of aquaculture in a more crowded world striving to be resource-efficient and sustainable. Ostrom has studied how humans interact with ecosystems in common pool resource systems, emphasizing the value of self-organization, stakeholder engagement due to the complexity of issues, the diversity of actors involved and the growing scarcity of resources that have to be shared. Her proposal is that of a local, “polycentric approach”, where key management decisions should be made as close to the scene of events and the actors involved (Ostrom, 1990; Ostrom, Gardner and Walker, 1994). Examples of the merits of such approaches to smallholder aquafarmers now exist, especially in Asia (De Silva and Davy, 2010).

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Novel and emerging technologies: can they contribute to improving aquaculture sustainability?

Expert Panel Review 1.2

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Abstract

Aquaculture continues to be the fastest-growing food production sector with great potential to meet projected protein needs. The scientific and business communities are responding to the challenges and opportunities inherent in the

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growing aquaculture sector with research efforts generating novel technologies that mirror the diversity of the industry.

In genetics and breeding, the pace of advancement and innovation has been increasing exponentially. The number of breeding programmes, diversity of species, target traits and efficiency and sophistication of techniques applied continues to expand and advance. However, the pace of scientific development has at times outdistanced our ability to analyze risks and benefits, develop appropriate culture and containment technologies, educate and communicate, and reach policy and regulatory consensus. Now, more than ever, efforts must be made for society to accurately analyze and understand risks, to capture opportunities to raise healthier aquatic organisms faster with less environmental impact, while improving economic stability and providing associated social benefits.

Disease outbreaks continue to constrain aquaculture sustainability. Improvements in aquatic animal and plant health are coming from new technologies, improved management strategies and better understanding of the genetic and physiological basis of immunity. Vaccine development is benefiting from better specific antigen determination, more efficacious adjuvants and enhanced vaccine delivery. Traditional diagnostic technologies and newer methods have greatly improved speed, specificity and sensitivity. Research on improving oral delivery and disease management strategies that focus on prevention offer opportunities for improved control of pathogens and parasites in the future, obviating the use of antibiotics and chemotherapeutants.

An important key to culture of any fed species is the development of sustainable, cost-effective and nutritionally complete feeds, along with efficient feed management systems. Current research is focusing on improved understanding of nutritional requirements, nutrient availabilities and cost-effective formulations designed to maximize food conversion efficiency. Continuing cost pressures and the acute need to find additional protein and lipid sources to augment limited fishmeal and fish oil supplies is driving an increased understanding of how different nutrients are utilized and how to use increasing amounts of terrestrial ingredients. New sources of proteins and lipids from algae and microbes can offer alternatives, as cost efficiencies improve. Use of enzymes, probiotics and prebiotics, phytogenic compounds and organic acids are being shown to change gut microflora and improve health, digestibility and performance. Improved pelleting and extrusion technologies allow the production of top-quality feeds.

Advancements in production systems, including recirculation technologies, cages and integrated multi-trophic aquaculture, are also contributing to industry expansion and sustainability. All of these production system technologies are benefitting from expanding information and communication systems which are enabling advances in every stage of production. These and other examples

suggest some of the benefits that future scientific-based innovation will contribute towards meeting increasing food demands, while improving social, environmental and financial sustainability of the global aquaculture industry.

KEY WORDS: *Aquaculture, Breeding, Feeds, Genetics, Novel technologies, Pathogens, Production systems, Sustainability.*

Introduction

Aquaculture continues to be the fastest-growing food production sector. The expansion of world populations and continuing problems with food deficits in many parts of the world stresses the need for additional/new sources of protein. In parallel, current trends suggest an increasing demand for high quality seafood from an expanding middle class, as countries like China continue to experience significant economic growth. It is recognized that sustainable aquaculture can contribute to solutions which can reduce pressures on wild caught fisheries while efficiently producing high quality protein. It has been suggested that aquaculture could provide new opportunities for food production from the sea and for efficient production systems on land which could expand food production within limited land and water resource constraints. Meeting these needs and achieving these goals will require innovation to refine existing aquaculture techniques and to apply new technologies to responsibly expand production. The scientific and business communities are responding to the challenges and opportunities inherent in the growing aquaculture sector with research efforts generating novel technologies that mirror the diversity of the industry. The present review provides an overview of some of the areas of current innovation in aquaculture. Sections on genetics and breeding, health, nutrition, sustainable production systems and information technology provide a review of some of the important trends in current and emerging research and development directions.

Genetics and breeding

Breeding and genetic selection

It is well known that genetic improvements have made tremendous contributions to assuring sustainable supplies of food for expanding world populations. For example, the often cited research by Havenstein, Ferket and Qureshi (2003) elegantly demonstrated that “genetic selection brought about by commercial breeding companies has brought about 85 to 90 percent of the change that has occurred in broiler growth rate over the past 45 years. Nutrition has provided 10 to 15 percent of the change”. The selected birds were estimated to have a feed conversion ratio (FCR) of 1.62 and 1.92 on the 2001 and 1957 feeds, respectively, with average body weight (BW) of 2 672 and 2 126 g. The unselected controls demonstrated FCRs of 2.14 and 2.34, with average BW of 578 and 539 g. As described below, examples are emerging in aquaculture-

related literature demonstrating rates of relative genetic gain which can equal or exceed those described above for poultry. With their high fecundity and in many cases shorter life spans than terrestrial livestock and poultry, aquatic animals are excellent candidates for selective breeding programmes. However, aquaculture, with a few exceptions, remains an industry based on the culture of mostly unselected, semi-natural stocks and/or isolated populations subject to inbreeding and/or unintentional selection (Lutz, 2001). Aquaculture producers in many rural areas in developing countries have little understanding of, or interest in genetics in general, and in the rapidly advancing science of molecular biology, in particular. Meeting future demands for sustainable supplies of farmed seafood will depend upon continued progress in implementing practical methods of genetic improvement at all levels of the industry. This can be achieved through improved training and extension, continued investment in professionally managed breeding programmes and expanded access to improved stocks.

Species selection and establishment of founder stocks

Classical breeding programmes (i.e. selective breeding, crossbreeding and hybridization) are the mainstream of finfish genetic improvement (Bartley *et al.*, 2001; Gjedrem, 2005; Hulata and Ron 2009). The impact of selective breeding programmes on the aquaculture industry can be exemplified by the wide global distribution of the Donaldson strain of rainbow trout (*Oncorhynchus mykiss*) (Parsons, 1998), the success of the Norwegian Atlantic salmon (*Salmo salar*) breeding programme (Gjedrem, 2000) and the progressing dissemination of the selectively bred Nile tilapia (*Oreochromis niloticus*) known as genetically improved farmed tilapia – GIFT (Pullin, 2007). From 2000 to 2005, global production of essentially unselected strains of giant tiger prawn (*Penaeus monodon*) has levelled at about 700 000 tonnes. On the other hand, worldwide production of whiteleg shrimp (*Litopenaeus vannamei*), predominantly from domesticated and selectively bred broodstock increased from about 200 000 tonnes to over 1.6 million tonnes over the same period (Preston *et al.*, 2009). Based on the initial isolation of specific pathogen free (SPF) founder stocks, breeding programmes with *L. vannamei* have focused on maintaining biosecure SPF breeding populations, individual selection for growth and family selection for disease resistance (Browdy, 1998). Domestication and breeding of *L. vannamei* has significantly improved the economics and reliability of shrimp farming (Wyban, 2009). Whereas in the past, improving growth rate was the most common breeding goal, new traits have been incorporated more recently into breeding programmes. These include production-related traits (such as age at maturity; eliminating vertebral deformity; feed efficiency; and resistance to stress, diseases and parasites) and consumer-related traits (such as appearance, body composition and carcass quality). As fish welfare is becoming a crucial issue for the aquaculture industry (Ashley, 2007), attention has also been given to animal welfare-related traits (Olesen, Groen and Gjerde, 2000; Bentsen and Olesen, 2002; Olesen *et al.*, 2003). Attention is also given to the possible effects of selection on the social behaviour and growth pattern of the fish (Brännäs *et al.*,

2005). Improvements also have been made in breeding programmes through the introduction of new methodology for measuring complex traits, such as flesh color or feed efficiency (in rainbow trout – Helge Stien *et al.*, 2006; Kause *et al.*, 2006).

Breeding strategies

Efforts have been made recently to optimize mating designs for reducing effects of inbreeding (Gjerde, Gjøen and Villanueva, 1996; Villanueva, Woolliams and Gjerde, 1996; Sonesson and Meuwissen, 2000, 2002; Sonesson, Janss and Meuwissen, 2003; Gallardo *et al.*, 2004; Dupont-Nivet *et al.*, 2006; Holtsmark *et al.*, 2006, 2008; D'Agaro *et al.*, 2007) and in improving the experimental designs and statistical models to enhance genetic gains (Sonesson, Gjerde and Meuwissen, 2005; Hinrichs, Wetten and Meuwissen, 2006; Martinez *et al.*, 2006a,b). In addition, emerging technologies based on molecular markers and genomic approaches progressively rise in importance, and efforts are made to involve molecular approaches in breeding programmes (Fjalestad, Moen and Gomez-Raya, 2003; Silverstein *et al.*, 2006). A step further towards improving the design of a breeding programme was taken by Hayes, Moen and Bennewitz (2006) in their comparison of different strategies for using molecular marker information in order to maximize genetic diversity in the base population. Combining available phenotypic information for the traits of interest with marker data, they would “ensure that as much genetic variance as possible, for as many traits as possible, is captured in the base population”.

The use and exchange of aquatic genetic resources (AqGR) have been crucial elements in facilitating aquaculture's fast growth (the fastest in the food-producing sector) over the last three to four decades. A special issue of *Reviews in Aquaculture* featured a series of reviews on genetic resources of species and species groups of important cultured aquatic organisms, for food production purposes, and issues related to the use and exchange of genetic resources thereof (Bartley *et al.*, 2009). The papers describe a variety of uses of AqGR that include breeding and genetic improvement in aquaculture, supporting culture-based fisheries (Solar, 2009); culture of marine shrimp (Benzie, 2009), common carp (*Cyprinus carpio*) (Jeney and Zhu, 2009), Nile tilapia (Eknath and Hulata, 2009), bivalve molluscs (Guo, 2009), salmon (Solar, 2009) and striped catfish (*Pangasianodon hypophthalmus*) (Nguyen, 2009); providing bait fish (Na-Nakorn and Brummett, 2009); producing ornamental species (Nguyen *et al.*, 2009); and mass cultivation of seaweeds (Yarish and Pereira, 2008).

Issues related to biosecurity, guidelines for the transfers of stocks and assuring pathogen status of genetic strains must be considered in the development and dissemination of selected stocks and improved strains. As mentioned above, for penaeid shrimp, the exclusion of listed pathogens from breeding centers and maintenance of stocks free of specific pathogens was a critical component in the development of selective breeding for *L. vannamei*. International Council for

the Exploration of the Sea (ICES) guidelines were followed in the collection of founder stocks and a hierarchy of breeding centers, multiplication centers and hatcheries supported by careful attention to pathogens of concern were critical components of the breeding programme (Browdy, 1998). Thus, attention to issues related to disease control and pathogen transfer should be an important consideration in the management and regulation of sustainable aquaculture development.

Risks associated with selective breeding programmes should not be ignored. Species or strains of many fish species have been translocated from their place of origin or from places to which they have been introduced, and deliberately released for stocking or escaped from culture facilities, thereby affecting wild stocks (Cross, 2000). For example, the farming of Atlantic salmon, which has greatly expanded in the last 50–60 years, resulted in large numbers of escaped farm salmon invading native salmon populations throughout the North Atlantic (Fleming *et al.*, 2000; Carr and Whoriskey, 2006; Gilbey *et al.*, 2005; Hindar *et al.*, 2006; O'Reilly *et al.*, 2006). The nature of this interaction has been investigated by McGinnity *et al.* (2003, 2004), Weir *et al.* (2004, 2005) and others. Escaped salmon from net-pen aquaculture may have various potential biological consequences, e.g. risk of feral stock establishment; risks of competition with wild fish for mates, space and prey; risk of pathogen transmission; and risks associated with genetic interactions with wild stocks (Naylor *et al.*, 2005; Verspoor *et al.*, 2006). Culture of Atlantic salmon has also been shown to genetically affect wild populations of other salmonids, e.g. sea trout (*Salmo trutta*) (Naylor *et al.*, 2005; Coughlan *et al.*, 2006). Additional concerns are the potential risks associated with Atlantic salmon selective breeding programmes and translocations of stocks in and between Europe, North America and Chile.

The effects of cultured species on their respective wild populations are visible in the last two or three decades also with the Mediterranean gilthead seabream (*Sparus aurata*) and the European seabass (*Dicentrarchus labrax*). These effects include interaction and competition for resources by accidentally escaping fish (whose numbers are increasing according to the records) and contribution of escaped fish to reproduction in the wild (Dimitriou *et al.*, 2007).

Tilapias are a group of fish that have been widely spread around the world during the last 50 to 60 years (Pullin *et al.*, 1997). More recently, stocks of Nile tilapia were introduced from various regions in Africa into the Philippines and mixed with cultured (earlier-introduced) strains to form the base population for the GIFT breeding programme carried out by the WorldFish Center (formerly ICLARM) and collaborators (Eknath *et al.*, 1993, 2007; Eknath, 1995). Improved descendants from this programme were disseminated to several countries in Southeast Asia for evaluation against local stocks, eventually leading to commercial culture of this introduced strain, which showed superior growth rate and survival relative

to that of other strains used by farmers (De Silva, 2003). Since no native wild populations of tilapia existed in those countries, escapement did not result in any damage to wild tilapia populations. Upon termination of the GIFT research programme, subsamples were transferred to several countries in the region and served as founders for separate, parallel, further breeding programmes (Gupta and Acosta, 2004). The arguments for and against using improved GIFT strain in aquaculture in Africa are summarized in Brummett and Ponzone (2009).

Future trends and prospects

Conventional breeding programmes will continue to be the main engine driving the global aquaculture industry forward. Efforts will persist to increase efficiency and optimize the design of breeding programmes by maximizing the use of pedigree information while using both established and cutting-edge technologies mentioned above. However, since these methods are less suitable for economically important traits that are difficult to measure on candidates for selection (such as carcass and disease traits), alternative approaches will have to be further developed and optimized. Here is where incorporation of recent biotechnological tools may come into play. The potential for accelerating breeding programmes expected from applying these tools has yet to be realized in the aquaculture industry. Nevertheless, marker-assisted selection (MAS) and gene-assisted selection (GAS) methodologies, when mature, may eventually become practical in efforts towards identifying genes that underlie economically important traits and towards combining quantitative and molecular data in breeding programmes. A potentially alternative breakthrough may arise from solving containment problems, currently limiting the use of genetically modified (GM) aquacultured organisms; with education and accumulation of data, antagonism of the public to the use of genetic modification may fade.

Genome-based technologies

DNA marker technologies

DNA marker technologies have been developed to reveal and differentiate genomic variations within a population, among populations or among various other higher levels of taxa. For fisheries and aquaculture purposes, such genomic variations are studied in relation to phenotypic performance of the fisheries population or aquaculture broodstocks.

The entire task of DNA marker technologies is to provide the means to reveal genome variations, in particular the indels (involving insertion or deletion of one or more bases) and the single nucleotide polymorphisms (SNPs – substitutions in bases at any given site of DNA) represent the vast majority of genomic variations. In the last 30 years, several DNA marker technologies have been developed, including restriction fragment length polymorphism (RFLP, for recent reviews, see Liu, 2007, 2009), microsatellites, rapid amplification of polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP) and SNP

RFLP is an old technology. Due to its relatively low polymorphic rate and low ability to differentiate genomic variations, RFLP is no longer frequently used in most genomic settings, although it is still used in some fisheries and aquaculture settings.

Microsatellites are simple sequence repeats (SSRs) of 1–6 base pairs. The variation of the number of repeat units causes microsatellite polymorphisms. The advantages of microsatellites include their abundance in genomes, even distribution, small locus size facilitating polymerase chain reaction (PCR)-based genotyping, co-dominant Mendelian inheritance and high levels of polymorphism (for recent reviews, see Liu, 2007, 2009). The disadvantages of microsatellites include the requirement for existing molecular genetic information, a large amount of up-front work for microsatellite development, and the tedious and labour-intensive nature of microsatellite primer design, testing and optimization of PCR conditions. Over the past decade, microsatellite markers have been used extensively in fisheries and aquaculture research, including studies of genome mapping, parentage, kinships and stock structure.

At the beginning of the 1990s, efforts were devoted to develop multi-loci, PCR-based fingerprinting techniques. Such efforts resulted in the development of two marker types that were highly popular at that time: RAPD (Welsh and McClelland, 1990; Williams *et al.*, 1990) and AFLP (Vos *et al.*, 1995). RAPD has been widely used in genetic analysis of fisheries and aquaculture species, but its further application in genome studies is limited by its lack of high reproducibility and reliability. In addition, RAPD is inherited as dominant markers and transfer of information with dominant markers among laboratories and across species is difficult. AFLP is based on the selective amplification of a subset of genomic restriction fragments using PCR (for recent reviews, see Liu, 2007, 2009). AFLP combines the strengths of RFLP and RAPD. It is a PCR-based approach requiring only a small amount of starting DNA, it does not require any prior genetic information or probes, and it overcomes the problem of low reproducibility inherent to RAPD. It is particularly well adapted for stock identification because of the robust nature of its analysis. The other advantage of AFLP is its ability to reveal genetic conservation as well as genetic variation. The major weaknesses of AFLP markers are the dominant nature of inheritance, the technically demanding procedures and the requirements for special equipment such as automated DNA sequencers for optimal operations.

SNP describes polymorphisms caused by point mutations that give rise to different alleles containing alternative bases at a given nucleotide position within a locus (for recent reviews, see Liu, 2007, 2009). Recent technology breakthroughs have brought SNPs to the center of genetic and genomic applications, becoming the markers of choice in the future. They are very abundant in genomes. They allow comparative mapping analysis and are amenable to automated large-scale genome analysis. The real challenge now is SNP discovery. As reflected in its

definition, SNP discovery depends on sequencing. Sequencing a huge number of genome segments representing the same sequences from independent chromosomes was a daunting task. However, recent development of the next generation sequencing has made it readily possible for many fisheries and aquaculture species using state-of-the-art equipment.

In spite of the current lack of draft whole genome sequences for aquaculture species other than nori (Gantt *et al.*, 2010), it is anticipated that they will soon become available for other major aquaculture species. Once genetic linkage maps are well constructed, genome scans for quantitative trait loci (QTL) are expected to follow to study traits which will be important targets for marker-assisted selection. As SNP markers are great markers for the analysis of trait-genotype associations, their application to aquaculture will become essential. SNPs will likely become the major markers of choice for genome research and genetic improvement programmes in aquaculture. Marker-assisted selection or whole genome-based selection in aquaculture should provide unprecedented genetic gains and benefits.

Genetic modification

The successful transfer of foreign gene constructs into a new host has been demonstrated for several fish species over the past 20 years. Short gene constructs have been inserted into breeding populations of fish, resulting in significant gains in traits of interest such as growth, disease resistance and cold tolerance (Lutz, 2001; Rasmussen and Morrissey, 2007). A number of techniques have been developed for introducing the genetic constructs achieving incorporation, expression and passing of the genes to subsequent generations of fish. The technology for creating transgenic animals is constantly improving, overcoming current limitations and providing potential alternatives for breed improvement. While overcoming potential technical problems with transgenic fish, the major constraints to adoption of transgenic stocks in aquaculture are the development of regulatory policies, the assessment of environmental and food safety risks and the acceptance of these technologies by consumers.

Recently, Kapuscinski *et al.* (2007) have published a book detailing options for comprehensive science-based risk assessment and risk management for genetically modified fish. The authors conclude that, realizing the potential of transgenic aquaculture to be of best use for society, its risks must be honestly and accurately analyzed and understood. The book details transparent, flexible, participatory and scientifically sound processes of risk assessment and management. They suggest practical guidelines to begin the process proactively using a safety-first approach and proceeding on a case-by-case basis. As the technologies for gene transfer continue to advance, there will be a growing need for these types of approaches to focus on reducing probability of unanticipated and unacceptable environmental risks while facilitating responsible utilization.

Genome mapping

The genome of a species of interest can be mapped genetically using recombination points as references, or physically using DNA segments as references. Both genetic linkage maps and physical maps are very important. Genetic linkage maps are required to study performance and production traits, while physical maps are required to study the genes involved in the determination of performance and production traits. Genetic linkage mapping involves analysis of performance trait(s) in relation to the markers on the chromosomes. Genetic linkage maps have now been made with many of the aquaculture species, such as Atlantic salmon, tilapia, catfish, rainbow trout, Atlantic cod (*Gadus morhua*), seabream and European seabass. Mapping performance traits by genetic linkage analysis is referred to as QTL mapping, as most, if not all, performance traits are controlled by multiple loci. QTL mapping provides information as to where the genes controlling the performance trait(s) are located in relation to the segregating markers. However, without a physical map, one can just get some information as to which markers are close to the QTL, but cannot easily conduct detailed analysis of candidate genes controlling the traits. Once the physical map is available, sequence-tagged markers on the genetic linkage map can be located on the physical map, and this process is referred to as map integration. Upon integration of genetic linkage and physical maps, genomic segments involved in QTL can be identified. If the genomic segments involving the QTL are relatively small, one can determine what genes are included in the segment(s), thereby identifying candidate genes for the involved performance traits. Practical application of QTL mapping is marker-assisted selection. Fuji *et al.* (2007) reported an example of practical application of marker-assisted selection to develop a population of lymphocystis disease-resistant Japanese flounder (*Paralichthy olivaceus*). It is anticipated that in the future whole genome-based selection programmes will be developed for aquatic species, as is already occurring in terrestrial livestock species (Liu, 2009).

Genome sequencing

The purpose of whole genome sequencing is to decode the entire genetic composition of an organism through DNA sequencing. Whole genome sequencing used to be very expensive, so it was not financially possible for fisheries and aquaculture species. However, the availability of the next generation sequencing technologies has made it much cheaper to sequence the genomes of aquatic organisms, most often within a million dollars. Most recently, several whole genome sequencing projects involving aquaculture species are underway, including Atlantic cod, Pacific oyster (*Crassostrea gigas*), Atlantic salmon, channel catfish (*Ictalurus punctatus*), tilapia, nori (*Porphyra*) and several other species. Whole genome sequences will serve as the most detailed linkage and physical map of the genome, with every base pair of the vast majority of the genome known. Whole genome sequencing also generates large numbers of SNPs for the analysis of trait(s). Once the association of SNPs with traits is known through genetic studies, candidate genes can be identified and tested.

Functional genomics

Environmental or physiological stimuli including physical, chemical biological, metabolic hormonal or disease stresses induce changes in the expression of an organism's genome, the results of which determine the type, level and effectiveness of the response. The application of new genomic analysis technologies to aquaculture species can be applied to generate a wealth of data on molecular response mechanisms. The study of the function of genes and genome segments has been facilitated by the increasing data on genome sequences. Sequencing of expressed sequence tags (ESTs) has been the primary approach to gene discovery in aquaculture species. New approaches based on next generation sequencers should quickly increase our understanding of genes of important aquaculture species through *de novo* sequencing of whole transcriptomes. ESTs are single pass sequences of random complementary DNA (cDNA) clones. Random clones are sequenced from cDNA libraries extracted from target tissues of organisms of interest. The rate of gene discovery is rapid at first, but it drops precipitously once commonly expressed genes have been collected. Normalization techniques can then be used to collect more rarely expressed genes. The most immediate information gained from analysis of EST collections is the existence of genes structurally related to those present in other organisms, which are likely to play roles in important physiological processes. A second level of information arising from EST analyses relates to levels of expression, as well as tissue distribution of specific transcripts. Abundance of an mRNA is often (but not always) directly related to the frequency at which ESTs representing it are present in a particular library. From this information, relative levels of expression for different genes can be inferred, which provides a first level of functional insight, even for genes for which activities cannot be predicted from sequence alone. This becomes particularly important in the study of invertebrates, where less fundamental information may be available (Robalino *et al.*, 2009).

Even with every single base pair sequenced, the function of genes and genome segments is largely unknown. However the development of new tools for functional genome analysis is proving new ways to gain insights into gene function. One of the most important of these tools is the use of genome scale expression analysis using microarrays or next generation sequencing. Liu (2009) provides a tabular summary of the current status of microarray development in aquaculture and aquatic species. A microarray is an arrayed series of thousands of tiny spots of DNA which can then hybridize with messages in an unknown sample, providing information on the abundance of nucleic acid sequences in the target sample. This then corresponds to up or down regulation of genes, providing data on tens of thousands of genes simultaneously. This information can be used to classify the physiological state of the organism from which the sample was collected or to generate data on the up and down regulation of specific genes. For example, in shrimp, our understanding of antiviral responses is quite limited, this despite the tremendous economic significance of viral

epizootics in shrimp culture. Using advanced genomic tools including a first and second generation microarray, much has been learned about specific genes and genetic pathways, about the importance of antimicrobial peptides and about the function of double-stranded RNA as an inducer of antiviral immunity (see Robalino *et al.*, 2009 for review).

In well-studied model species such as the mouse or rat, gene functions are most often studied by gene knockout, i.e. upon knockout of a gene, one can determine what functions are lost. These types of studies are being carried out in shrimp using gene silencing to better understand the function of genes and proteins (e.g. de la Vega *et al.*, 2008). However, in most fisheries and aquaculture species, gene knockout has not been possible, although some studies on model species are ongoing.

Future trends and prospects

In the future, genetics approaches will allow identification of the genomic locations that are involved in certain functions through QTL or whole genome association studies. Coupling of location candidate genes with expression candidate genes may allow further narrowing down to the real candidate genes. Combining direct approaches and comparative genomic analysis will be very useful. For instance, if a gene is well studied to have certain functions in one organism, it is possible and perhaps likely that the ortholog of this gene would have the same or similar functions in related organisms. In this regard, functional studies using model species such as zebrafish (*Danio rerio*), pufferfish (*Fugu rubripes*), and medaka (*Oryzias latipes*) can lend much to functional studies in fisheries or aquaculture species. Upon the availability of the whole genome sequence assembly, the assignments of orthologs will become possible.

Although the pace of advances in genetic enablement has been accelerating as its potential is realized in aquaculture, significant challenges remain:

- The tremendous variety and diversity of aquaculture species often results in competition and division of limited resources among an expanding number of species. In some cases, much can be learned from closely related organisms, but much effort must be invested in each target species to achieve maximum results. Achieving consensus on highest priority species could improve the pace of discovery.
- Despite continuing improvements in lowering the cost of high throughput genetic technologies, the expense of a well-designed selection programme and the investments necessary for application of advanced genomic tools will limit private-sector adoption to large-scale integrated companies or well-funded specialty firms. National and multinational scientific consortia could accelerate advancement and transfer of technologies to the private sector.
- Biosecurity and problems with controlling pathogens in the aquatic environment will continue to constrain genetic improvement efforts unless carefully controlled.

- Breeding programmes and genomic tools quickly generate very large volumes of complex data. Attracting skilled individuals and applying necessary computing resources to aquaculture bioinformatics applications will be a key to future success.
- A final critical prerequisite to the safe and sustainable application of genetic technologies for aquaculture continues to be the development of and investment in educational resources and policy and regulatory tools. Implementation of the great potential of genetically improved aquaculture species will depend upon its practitioners, consumers and regulatory authorities having a clear understanding of the risks and benefits. This, in turn will allow the reasoned application of practical and precautionary approaches which will enable safe and sustainable implementation.

Health

Managing the health of aquatic organisms has proven to be one of the greatest challenges and opportunities for expansion of sustainable production of cultured seafood. Epizootic outbreaks of disease continue to represent one of the most important limiting factors for the success of aquaculture production systems in different countries in the world. The worldwide movement of live (i.e. eggs, gametes, larvae, juveniles and broodstock) and frozen aquatic animals is necessary for the development of aquaculture. However, it has also provided opportunities for rapid transmission and trans-boundary spread of diseases, causing adverse socio-economic losses in the aquaculture food-producing industry (Bondad-Reantaso *et al.*, 2001; OIE, 2009a, b; Lightner *et al.*, 2009; Walker and Mohan, 2009). In response, aquaculture researchers and industry have developed new technologies and improved management techniques. The efforts have focused on diagnostic technologies, epidemiology and disease exclusion. This section elaborates on some recent developments and their potential application for improving aquaculture sustainability.

Diagnostic technologies

Most currently available aquaculture diagnostic technologies are based on traditional methods used in bacteriology, virology, mycology and parasitology. Over the last two decades, significant efforts have been invested in development of more advanced methods (OIE, 2009a, b). As a result, routine histopathology and classical microbiology have now been widely supported by a significant number of immunodiagnosics (immunohistochemistry (IHC), direct or indirect fluorescence antibody (FAT/IFAT), enzyme-linked immunosorbent assay (ELISA), immunochromatography (ICT)) and conventional nucleic acid-based approaches such as *in situ* hybridization using pathogen-specific gene probes, polymerase chain reaction (PCR), reverse transcription-PCR and quantitative real-time PCR (qPCR) (OIE, 2009a, b). The last is the latest improvement over the standard PCR techniques. Perhaps the most refined diagnostic technology currently available is the development of qPCR, especially using TaqMan® probe, because

it provides quantitative detection of a specific target with higher specificity and sensitivity. A limited but growing number of protocols, reagents and kits are currently available for aquaculture pathogen detection based on some of the technologies listed above. Monoclonal antibodies (mAbs) are being produced as standard reagents for diagnostic tests and are available commercially (Adams and Thompson, 2008). Aside from more secure diagnosis, their commercial production will make a significant contribution to sustainability of aquaculture when used for disease surveillance, as large numbers of animals can be screened non-destructively for previous exposure to selected pathogens. Furthermore, they can be used for post-vaccination efficacy testing, as well as for testing wild stocks.

Today, laser-based capture micro-dissection is an emerging technology enhancing histopathology to allow researchers to precisely isolate specific pathogens from tissue sections, even with mixed infections. These then can be isolated for nucleic acid extraction and molecular diagnostic, genetic and proteomic analysis (Small *et al.*, 2008). The implementation of histology-based virtual microscopy (VM) is also an emerging technique. VM allows storage of a complete clinical and pathology workup consisting of several images which are stored in a dedicated server database. This facilitates rapid effective case management and communication for teaching or for off-site diagnostic review. The use of digital slides also represents a powerful tool for the assessment of diagnostic accuracy and quality control programmes for diagnostic laboratories in different parts of the world (see the European Union (EU) funded research programme BEQUALM available at www.bequalm.org/fishdisease.htm, Rocha *et al.*, 2009). Time consuming conventional methods for bacterial identification are being replaced by a strip-concept of dehydrated biochemical tests (enzymatic and assimilation) in miniaturized microtubes (e.g. API 20 E). Moreover, a fully automated microbial identification and susceptibility system (VITEK) has been introduced for busier clinical laboratories and aquaculture certification programmes (Kuen, 2007).

An emerging platform combines end-point nucleic acid amplification such as PCR or loop-mediated isothermal amplification (LAMP) with dot-blot hybridization (DBH) or ICT. These emerging methods are allowing the development of highly specific, sensitive, rapid and cost effective methodologies for detection of pathogenic microorganisms which are less prone to contamination. In addition, these methods can be applied in resource-poor and “point-of-care” diagnostic settings (Teng *et al.*, 2007; Srisala *et al.*, 2008; Andrade and Lightner, 2009; Soliman and El-Matbouli, 2010). New dimensions are being opened for diagnostics with powerful multiplexing platforms for simultaneously testing for multiple different pathogens using emerging Luminex xMAP® and microarray technology. Although these technologies are just beginning to be applied for aquaculture, they are likely to become more widely used in aquatic animal diagnostic laboratories in the future (Adams and Thompson, 2008).

Many of these new diagnostic technologies can be tools in our efforts to improve the health of aquacultured animals. It is important to understand the advantages and disadvantages of each of these technologies, what kind of test is the most appropriate to apply in a specific disease situation and the type of conclusion that can or cannot be drawn from their results. Certification programmes for diagnosticians, for laboratories and for the methods themselves are currently limited, and governmental accreditation programmes would improve the outlook for more accurate and appropriate use of these powerful tools (Lightner *et al.*, 2009).

Epidemiology

The contribution of new diagnostic technologies to better understanding disease transmission and to epidemiological modelling can inform regulators and therefore contribute to determining constraints on movements of stock to better control spread of diseases across borders. Aquaculture epidemiological information has been routinely supported by a combination of molecular biology, bioinformatics and taxonomy to identify specific names and biological properties of the new and emerging infectious agents or strains. For example, retrospective molecular sequence analysis of the evolutionary story of etiological agents corroborated suspected transboundary routes of disease transmission and the characterization of emerging circulating strains in aquaculture operations around the world (McBeath Alastair, Bain and Snow, 2009; Wertheim *et al.*, 2009; Muller *et al.*, 2010).

Surveillance has become more important since the formation of the World Trade Organization (WTO) and subsequent implementation of various multilateral agreements on trade aimed at reducing the risk of international spread of important aquatic animal diseases, early warning of disease outbreaks, planning and monitoring of disease control programmes, provision of sound aquatic animal health advice to farms, certification of exports, as well as international reporting and verification of freedom from particular diseases. Geographic information systems based on remote sensing and mapping have also emerged as a powerful analytic and decision-making technology to assist epidemiologists in government, industry and reference laboratories to minimize the likelihood of rapid spread of disease in aquaculture operations (Kapetsky and Aguilar-Manjarrez 2007; Bayot *et al.*, 2008).

Vaccines

Vaccine development is benefiting from new technologies in three main ways, i.e. by specific antigen determination, more efficacious adjuvants and vaccine delivery. Most commercial vaccines are against bacteria, a few against viruses and none against parasites. Most are inactivated bacterial pathogens, and there are a few commercial vaccines which are live attenuated pathogens. Using molecular technology, pathological organisms can be genetically modified to remove the virulence genes to avoid reversion and, therefore, are more

sustainable. The advances in DNA recombinant vaccines are most promising and more sustainable because they reduce concerns for the environment and for the consumer (Somerset *et al.*, 2005; Kurath, 2008). DNA vaccines, based on administration of a plasmid encoding the gene for the selected antigen, have been under development for a number of years. Progress has been restrained by environmental and safety concerns by regulators and by confusion with genetically modified organisms (GMOs) by consumers (Lorenzen and LaPatra, 2005). Once these problems have been overcome, DNA vaccines may make a considerable contribution to fish welfare. These new technologies coupled with proteomics may well open up the way for parasite vaccines. Until recently, these vaccines have been constrained by difficulties in finding protective antigens, but breakthroughs for parasites like sea lice may be on the horizon (Ross *et al.*, 2008). Proteomics and epitope mapping can be used for precise identification of specific antigens and to monitor efficacy and duration of response.

Adjuvant research has accelerated in recent years, benefitting from advances in mammalian vaccinology. This challenging research aims to improve vaccine response by increasing immunogenicity, focusing on co-stimulatory signals received from dendritic cells. Activity has concentrated on finding agents that activate dendritic cells to enhance effectiveness of vaccines as molecular adjuvants. Application of molecular tools is enabling cytokine discovery and elucidation of their role in the expression of co-stimulatory molecules (Secombes, 2008). Alongside the study of co-stimulatory molecules, there is the possibility of adjuvants which act to inhibit negative regulators.

Currently, the most common procedure for vaccine delivery is by immersion or injection, both of which have their drawbacks. However, oral delivery systems are improving. Whereas the environment of the intestine has, to date, been seen as hostile to antigen integrity, it is now possible to protect it and release it in the most suitable environment, the hindgut. Poly (l:l) coated micro particles (PLGA) are revolutionizing delivery of antigens to immune cells for the induction of a long-lasting immune response for vaccination by promoting innate and adaptive immune responses in fish (Behera *et al.*, 2010).

Dietary supplements

The use of dietary supplements and nutritional strategies which may modulate overall fitness, gut health and immune responses is discussed below in the Nutrition section. Use of immunostimulants and stress diets to improve the defense of animals during critical stressful periods, have been promoted in the commercial feed sector. Compounds have been suggested such as β -glucans, bacterial products and plant derivatives which have the potential to activate the innate defense mechanisms by acting as receptors which trigger gene activation (Galindo-Villegas and Hosokawa, 2004). Probiotics and prebiotics are at a similar stage in research, attracting much attention (Balcázar *et al.*, 2006). Organic acids and essential oils have been suggested to modulate gut microbial

communities, improving resistance to some opportunistic enteric pathogens (Luckstadt, 2008). More information is necessary on the mode of action and the host/microbe interactions. It may be envisaged that useful products will be available in the future, contributing to greater sustainability by avoiding the use of drugs.

Chemotherapeutants

The greater efficacy and widespread use of vaccines will have the greatest impact on sustainability, by obviating the use of antibiotics and chemotherapeutants. There is little enthusiasm for the licensing of new antibiotics, and antiviral drugs have attracted little research interest in animal production industries. Chemotherapeutants have been, to date, essential for the control of parasitic diseases. However, issues relating to environment and consumer safety have been a powerful influence on the newer products under development. Avoidance of topical treatments using bath immersion applications have given way, where possible, to oral in-feed products for greater control of the active ingredients, less pollution and cost saving. Despite the need for new effective chemotherapeutants, costs and complexities of licensing constrain development. Owing to the concern for the natural environment, history of reduced sensitivity and product misuse in aquatic environments, the reaction from environmentalists and consumers has resulted in substantial regulation. The regulation of timing and rate of application of chemicals is likely to intensify. This, coupled with better monitoring, will encourage aquaculture to utilize more non-chemical control methods as part of an integrated pest management strategy (Sommerville, 2009). The use of multiple tactics against infection and greater regulation of drugs and chemicals will be major steps towards sustainability.

Disease exclusion

In the early years, aquaculture was plagued by misdiagnosed diseases in wild broodstock and seed. Presently, a variety of improvements have been made in applying biosecurity principles, best management practices (BMPs) and disinfection for control of pathogens. This has been facilitated by the development of more reliable and accurate diagnostic methods, application of educational approaches for training, use of better low water exchange management systems which reduce opportunities for pathogen introduction, improvement of feed formulations and advances in overall routine biosecurity and sanitation. Thus, over the past two decades strategies have been refined and adopted by many aquaculture operations based on use of a combination of i) early detection of specific pathogens over the time, ii) development of infrastructure for commercial supplies of healthy or SPF stocks, iii) improvement of stocks for desirable performance traits (i.e. disease tolerance, growth rate, feed conversion efficiency) and iv) development of consistent documented history for a particular stock assuring freedom from specific listed pathogens over time. As described above, major breakthroughs have been made in molecular techniques

in recent years which make the genetic selection for disease-resistant fish stocks a realistic possibility for the future, and this is accelerating as pedigree families become more available (Jones *et al.*, 2002). The rapid expansion of culture of whiteleg shrimp in Asia over the past decade exemplifies the potential for improvement of productivity through the use of healthy improved seed stocks coupled with biosecurity and disease management strategies. More detailed reviews on this topic can be found in Lightner *et al.* (2009) and Benzie (2009).

Future trends and prospects

The rapid expansion of aquaculture has provided opportunities for increased pathogenicity of existing infections and additional exposure to emerging disease etiologies. Although future success in realizing effective diagnostic or exclusion technologies for emerging diseases cannot be predicted, experience over the past 20 years suggests that many of the current strategies and advances reviewed here will facilitate future success in assuring aquatic animal health. This will depend upon continued advancement in several areas including:

- Developing accredited biosecure breeding programmes and expanding systems for health certification of stocks.
- Establishing and accrediting international reference laboratories and virtual international, national and regional surveillance systems.
- Accreditation and certification of diagnosticians, diagnostic laboratories and diagnostic methods.
- Developing improved reliable, rapid, accurate and ready-to-use multiplex kits for pond-side diagnostics.
- Identifying markers and exploring mechanisms of disease resistance.
- Expanding registration and availability of effective vaccines and of new methods for disease control and treatment.

Application of improved diagnostic technologies coupled with more thorough expanded epidemiology and disease exclusion efforts should continue to contribute to a more advanced and sustainable aquaculture industry for wholesome food production in the years to come.

Nutrition

The future of aquaculture nutrition will be based on a better understanding of the basic nutritional requirements and the role of gut microflora in the fish digestion process of a growing list of important cultured species, coupled with innovative solutions for delivering these nutrients in ways which minimize environmental impacts. The increasing demand for sustainable aquaculture products has focused attention on the need to improve feeds and feeding to allow increased production and productivity. Traditionally, aquaculture feeds, particularly for carnivorous and omnivorous species, were based on fishmeal and fish oil. These excellent ingredients are still the basis for many feeds today, but supply of fishmeal and fish oil is static. While there is strong evidence

that current production is sustainable, there is little prospect that additional production is likely. Inclusion rates are declining for major farmed species, but demand for protein and lipid (including essential fatty acids found in fish oil) is increasing rapidly as production of aquaculture species grows. Total replacement of fishmeal for some species (e.g. catfishes, carps and tilapia) is possible, and replacement of a significant proportion of the fishmeal and a lesser proportion of the fish oil for most species is relatively easily achieved. However, as availability declines and the need for more replacement increases, the task will become more difficult, particularly for fish oil. Hence, further research on suitable alternatives remains a very high priority (Tacon and Metian, 2008). A key driver for aquaculture production is the increasing need to minimize negative environmental impacts. As production intensifies, the impacts from uneaten feed and faeces on the receiving environment become more critical. Unfortunately, most ingredients available to partially or totally replace fishmeal and fish oil are less well utilized, increasing production of wastes. To address both these challenges, an improved understanding of the digestive physiology and nutritional requirements of key species is needed, a greater range of potential feed ingredients and new technology to improve their value needs to be evaluated and developed and continuing improvements made to processing technology used for producing feeds.

Nutrient requirements

Aquafeed development mirrors the history of development of prepared feeds for terrestrial agriculture. Over the past 50 years, terrestrial rations have reduced or eliminated the use of fishmeal as the price of this limited commodity has risen. Formulations have been consistently improved based on a fundamentally increasing understanding of the digestive physiology and nutritional requirements of poultry, ruminants and swine. One of the key accomplishments has been the ability to continue to meet the nutritional demands imposed by performance enhancements and physiological challenges resulting from aggressive selective breeding programmes. With recent advancements in the development of molecular genetic tools, the physiological demands of better-growing stocks will continue to increase along with more powerful scientific methods for the fine tuning of animal feed development. The ability to use a wide range of protein sources for terrestrial animal feeds, many of them inferior in terms of amino acid profile, was made possible by the development of cheap, effective crystalline amino acids that could be added in small amounts to meet deficiencies in lower cost ingredients. All of these trends have direct relevance to aquafeed advancement. In fact, many of these processes are occurring concurrently and, in some cases, at a faster pace. On the other hand, there are some fundamental differences which must be understood in the unique context of aquaculture. Perhaps the major difference is that aquaculture species are cold blooded and their aquatic habitat means they require less energy for thermoregulation, locomotion and protein catabolism. With some obvious exceptions, most species are not adapted to utilizing carbohydrates for energy. This means that

the total protein contents for nutritionally complete feeds are much higher than for terrestrial animals, limiting the choice of ingredients. Environmental variables directly influence nutritional demands, and species often face unique osmoregulatory challenges. For aquaculture species, feeds must be water stable, and poor-quality feeds can have the double negative of reducing growth performance and reducing water quality in the culture environment. Solubility in water can limit successful incorporation of key nutritional additives used in terrestrial animal feeds. Clearly, the number and variety of target species adds significant challenges in that research and development efforts must split between very different animal models. Thus, some of the most basic requirements remain undefined for many highly significant species. Meeting the needs of growers facing shrinking profit margins will depend upon the successful paradigm shift from formulation on the basis of ingredients to feeds based on a sound fundamental understanding of nutrition and physiology of the animal. This transition is well on its way with species like Atlantic salmon, tilapia, white leg shrimp and trout, while much more work is needed for emerging species like striped catfish and some marine carnivores.

Evaluation of ingredients

Evaluation of ingredients was not particularly important when feeds were composed primarily of fishmeal as a protein source and fish oil as a lipid source. Those ingredients are well digested and utilized by most species. However, alternative sources of protein and lipid are usually inferior in terms of matching amino acid and fatty acid composition to requirements. In addition, many alternative ingredients contain high levels of carbohydrate or ash that are not well utilized by most species. Antinutritional factors add an additional level of complexity. Key advances in this field have occurred with more structured methodology for ingredient evaluation and the identification of some additional ingredients that have high potential for increased use in aquaculture. Glencross *et al.* (2007) outline the steps involved in evaluation of ingredients. This starts with measurement of the energy and nutritional composition and examination for any contaminants. Secondly, the utilization of an ingredient and potential negative impacts on feed intake needs to be assessed to allow feed formulators to estimate maximum inclusion levels for different ingredients or combinations of ingredients. Different ingredients can affect energy or nutrient utilization and/or they can affect diet attractiveness and palatability. Both have an important impact on their value in practical diets. To discriminate these different effects, the inclusion of different ingredients at different concentrations needs to be assessed based on performance, feed intake and feed conversion efficiency. Finally, ingredient functionality should also be evaluated. This refers to the effects on physical properties of processed feeds. Ultimately, functionality also restricts the potential use of an ingredient. Regardless of how well an ingredient is utilized, if it cannot be used beyond a certain concentration because it negatively affects pellet stability, buoyancy or structure, the ingredient value is reduced.

New areas of ingredient evaluation include the application of molecular science, genomics and proteomics, where gene and protein expression are measured in response to different ingredient or dietary treatments. This study is often called nutrigenomics and is described by Pansert, Kirchener and Kaushik (2007). New advances in ingredient evaluation also include application of different techniques of analysis. Rapid analysis of ingredient composition, such as near-infrared spectroscopy (NIRS) is allowing real time analysis of ingredients from different batches and allows feed managers to fine tune formulations on the basis of small changes in ingredient composition for different batches (Glencross, 2009).

Ingredients

One of the greatest challenges for aquafeed development is reducing reliance on marine fish protein and lipid sources. Aquaculture feeds represent about 4 percent of total animal feed production while consuming over 68 percent of global reported fishmeal production and over 82 percent of reported fish oil production (Tacon and Metian, 2008). Moreover, continued growth of the sector has generated increasing price pressure on these limited commodities, particularly in El Niño years when supplies are limited. Higher prices coupled with increasing awareness of sustainability issues are resulting in decreasing inclusion rates and growing research into use of alternative protein and lipid sources (Tacon and Metian, 2008). In general, aquatic species have high protein requirements and low tolerance to carbohydrates in feeds (a large proportion of plant ingredients). For many warm-water species, there is also intolerance for high lipid contents, particularly those with high concentrations of saturated fatty acids. Depending upon the species, increasing use of many sources of vegetable proteins can limit availability of essential amino acids, cause problems with digestibility, increase concentrations of antinutritional factors, reduce palatability and affect physical properties of the feed. Many species, particularly marine carnivores, have high requirements for highly unsaturated fatty acids. Essential fatty acids such as docosahexaenoic acid (DHA) must be supplied from marine fish unless new alternatives are developed. Thus, there is an acute need for new nutritional technologies in this sector.

Despite limitations, a large and increasing number of ingredients have been evaluated for aquatic species, and use of these is increasing (see Gatlin *et al.*, 2007; Lim, Webster and Lee, 2008; Hardy, 2009, for reviews). The most common plant protein ingredient is soybean, soybean meal, and increasingly, soybean protein concentrate. This is a particularly valuable ingredient because of the huge volume of the grain produced in many countries and the global trade and availability. However, use in some species is restricted because of intestinal inflammation and the high content of non-starch polysaccharides and other carbohydrates that are poorly utilized by aquatic animals. Other plant ingredients that are being increasingly used include corn products (such as corn gluten meal), lupins and peas, canola, cottonseed meal and cereal products (wheat, rice and barley). Blending of ingredients can help to balance nutrient availability

while minimizing potential negative effects of individual plant-based ingredients. Protein concentration, through removal of the husk and other carbohydrate fractions, tends to improve the potential for use of plant-based ingredients, and future improvements may involve enzyme hydrolysis to improve digestibility. Some ingredients contain antinutrients that reduce their potential. Many are inactivated through heat (e.g. trypsin inhibitors); some (e.g. glucosinolates and erucic acid) have been reduced through breeding programmes. Other antinutrients include phytic acid, a mineral antagonist which may be overcome for some species using enzyme supplements and organic sources of minerals (Gatlin *et al.*, 2007).

Rendered animal products can be an excellent source of protein and lipid. Ingredients such as blood meal, meat and bone meal, poultry by-product meal and poultry oil have all been very effective in feeds for a number of aquatic species (see Li, Robinson and Lim, 2008; Shiau, 2008; Yu, 2008 for reviews). High protein meat meals (produced using processing by-products with less bone), have effectively replaced all the fishmeal in diets for some species (see Hernandez *et al.*, 2010 for a recent example). Constraints to use of rendered products include variability of composition, high content of total lipid and saturated fatty acids or ash in some products and potential contamination. In addition, use of rendered products can be constrained by labeling and regulatory issues and consumer acceptance. Other types of ingredients being used in aquaculture feeds include by-products from distilleries (including for biofuel production), microbial proteins, seafood processing waste and plankton and krill. New technologies for cost-effective production of microbial proteins from waste streams of food production may offer future opportunities to convert waste nutrients into valuable ingredients.

Alternative lipid sources to fish oil are being used in greater amounts (see Corraze and Kaushik, 2009 for review). Key alternatives include vegetable oils, preferably those with high omega-3 contents (e.g. canola) and poultry oil. Neither vegetable nor animal oils have comparable fatty acid profiles, and it is likely that fish oil will still be required for high-value species, larval stages with very high requirements for highly unsaturated fatty acids and for finishing diets. The production of marine microalgae, fungi or bacteria with very high contents of highly unsaturated fatty acids is currently prohibitively expensive for use in most aquaculture feeds but as production methods become more cost-efficient and competition increases, the situation is likely to change.

Prices for food and feed ingredients have been increasing and are likely to continue to increase due to rising demands from growing population, diversion of some grains for use in biofuels, increasing costs of production and transport, and changes in global trade. This will present challenges and opportunities in the aquaculture feed sector. The focus on carbohydrate-rich fractions for some products (e.g. biofuels) may provide an opportunity to use protein fractions for

feed ingredients. As mentioned above, new technologies are being developed to potentially improve the digestibility and nutritional quality of alternative feed ingredients. Protein concentrates, use of rendered ingredients and pretreatment with enzymes can offer higher quality alternative ingredients which improve performance, offering effective options when return on investment is factored in with feed ingredient costs. New sources of proteins and oils from algae and microbes may offer novel alternatives for meeting amino acid and highly unsaturated fatty acid (HUFA) requirements (Patnaik *et al.*, 2006; Kuhn *et al.*, 2009).

Other ingredients include enzymes which can act in the gut of the animal to improve digestibility, to minimize antinutritional factors or to release otherwise indigestible nutrients. For example, an increasing body of literature demonstrates efficacy of phytases in releasing phosphorus and improving mineral availability (Cao *et al.*, 2007). Low-cost enzymes are needed which can function in the gut of cold-blooded animals and are heat stable enough to withstand the rigors of the feed manufacturing process. Emerging technologies for improving the gut environment are being rigorously studied and are beginning to be applied in aquaculture feeds. Use of probiotics in feeds, although successful in human and animal nutrition, is not well accepted in aquaculture. Improved delivery methods and better understanding of gut microflora of aquatic animals could change this in the future (Balcázar *et al.* 2006). Similarly, prebiotics, essential oils and organic acids are being shown to change gut microflora, improving conditions for healthy gut flora while reducing concentrations of potentially pathogenic strains of bacteria (Luckstadt, 2008; Ringo *et al.*, 2010). With increasing use of alternative ingredients, addition of palatability enhancers and attractants may improve feed consumption (see Gatlin and Li, 2008 for a review on use of diet additives).

Feed production technologies

There are a number of different processing technologies to prepare ingredients and feeds. Washing, drying, grinding and classification are used to prepare some ingredients and to improve the nutritional value of others. Washing can remove water-soluble starch fractions in cereals, increase the protein content and remove some contaminants. Heating or cooking can remove trypsin inhibitors and other heat-labile antinutritional factors. Similarly, as protein molecules are heavier than non-protein fractions, fine grinding followed by air-classification has been used to produce protein concentrates for a number of plant protein sources. Removal of bones from source material for rendering plants will improve the protein content, and classification of dried, rendered product can be used to separate ash, also increasing the protein content. Clearly, altering processing conditions and source material can affect the composition of processing waste products.

There have been rapid improvements in processing technology for aquaculture feeds. For many years, feeds were produced using pellet presses, sometimes with steam conditioning to improve binding. The adoption of extrusion and

expansion technology has greatly improved the pellet quality of aquaculture feeds, the digestibility of some nutrients, particularly starch, reduced the amount of fines, and allowed some control of pellet buoyancy. Application of post-pelleting technologies such as vacuum coating, has allowed production of feeds with much higher lipid contents (e.g. for salmonid feeds) and opened the way for addition of enzymes, attractants, carotenoids and other heat-labile supplements.

Feeding systems

Improved feed management offers the potential to reduce feeding costs and improve environmental performance. Recent research has focused on determining optimal feeding frequencies and ration sizes for different species under different water temperature regimes. Improved feeding technologies based on automatic or demand feeding can reduce labour costs, decrease variability in application and offer new alternatives to reduce the soak time for bottom-feeding species such as shrimp. New feeding systems use technology to electronically monitor the number of uneaten pellets falling through sea cages and use those data to control additions of pellets. This technology has greatly improved apparent feed conversion ratios for some species. Even newer systems are being developed to use hydrophones to detect uneaten pellets in turbid ponds. This technology is likely to reduce feed wastage and improve the cost-effectiveness of aquaculture. Development of functional feeds designed for periods of stress or for different stages of the fish life cycle will provide new opportunities and new challenges for management of feeds and feeding in production facilities.

Future trends and prospects

The increasing volume of research publications and the application of new research tools is providing more information for researchers and industry. The development of alternative protein and lipid sources, development of new water-stable supplements and use of enzymes are providing more options than ever for least-cost high-performance formulations. An improving understanding of interactions between gut environment, nutrition and disease is providing alternatives to antibiotic therapies and holds promise for helping to control other diseases by improving host immunity, fitness and digestive health. Exigencies of the marketplace will drive the industry along the same lines as livestock, improving production efficiencies and allowing for greater output of high-quality sustainable products. Aquaculture will need to provide an additional 29 million tonnes per year of food fish just to maintain current consumption levels by 2030. New and innovative nutritional technologies will be an increasingly critical link in supporting future sustainable expansion of the sector.

Sustainable production systems

Traditional Asian aquaculture

Traditional Asian aquaculture systems have been reviewed recently by Edwards (2009). These systems are based on the use of locally available wastes and

by-products as nutritional inputs for the target crop. Edwards (2009) describes integrated agriculture/aquaculture systems, focusing on rice/fish integration, crop/livestock/fish integration in China and livestock/fish integration in many Asian countries. A second area of traditional practice is wastewater-fed peri-urban aquaculture, although reluctance and opposition to this type of culture system is growing as improving economic status leads to increasing demand for higher value fish. A third area of traditional culture is integrated fisheries/aquaculture fed low-value fish (“trash fish”). This practice expanded rapidly over the past two decades in Asia, but continued expansion is not sustainable due to problems with overfishing of vulnerable small wild fish, as well as issues with contamination of culture systems, introduction of pests and pathogens, generation of wastes and the availability of improved feed formulations. There is a significant research effort directed to reducing direct feeding of low-value fish to aquaculture species (Hasan and Halwart, 2009).

Research and development (R&D) has improved consistency and productivity in several areas. New methods are being developed to produce seed locally for expansion of small-scale traditional farming practices (Barman *et al.*, 2007). Opportunities exist for use of genetically improved strains and incorporation of health screening and management technologies to improve productivity. Better organization of the small farming sector locally and regionally can facilitate opportunities for application of new technologies to increase yields and reduce disease problems. Research on fertilization regimes has demonstrated financial and productivity advantages of supplementing organic inputs with small amounts of chemical fertilizers. Complexities increase as growers increase densities and begin to add formulated feeds. Traditional farming in many places is incorporating more modern methods, including the use of supplemental feeds that allow producers to increase productivity while maintaining principles of traditional aquaculture which utilize natural inputs and reduce wastes associated with more industrial monoculture (Edwards, 2009). Although traditional small-scale integrated agriculture/aquaculture systems allow for some productivity within a limited resource base, this type of aquaculture typically can support mainly household subsistence. This type of small-scale farming system will have a continuing role to play in providing contributions towards relatively poor rural household nutrition and income while allowing for a low-risk mechanism for farmers to gain aquaculture experience. However, Edwards (2009) suggests that future trends will be characterized by increasing motivation for maximizing income, leading to efforts to increase productivity, importation of nutrients from off the farm, specialization and a reduction in on-farm subsystems. Future development and research efforts should focus on medium-scale producers and application of appropriate technologies throughout the value chain to provide a basis of healthy seed, quality supplemental feeds and encouragement of cooperatives while enhancing ecologically based principles of traditional aquaculture which maximize cycling of nutrients within the system.

Integrated Multi-Trophic Aquaculture

Integrated Multi-Trophic Aquaculture (IMTA) is a technological innovation that builds upon the principles of some of the most ancient traditional agriculture and aquaculture practices which utilize waste from one sector of the farm as inputs/resources for another. Applying this ecologically based approach, modern aquaculturists envision IMTA systems as a promising means to utilize the nutrient waste from one feed receiving species to support grazers, filter-feeding organisms and primary producers. Whether land-based or around open water cages such organisms represent additional trophic levels, able to utilize what would otherwise be waste, and to allow added value for more efficient and sustainable production. Economic advantages include diversification of crops to provide additional income or a financial safety buffer in the event of problems with the primary crop. Environmental advantages include better efficiency of uptake of nutrients, reducing ecological footprint. Social and marketing advantages include improvement of perceptions of industrial aquaculture systems by local stakeholders and consumers. The aim is to increase long-term sustainability and profitability per cultivation unit (rather than per species in isolation, as in monoculture), as the wastes of one crop (fed animals) are converted into fertilizer, food and energy for the other crops (extractive plants and animals), which can in turn be sold on the market (Neori *et al.*, 2004; Robinson and Chopin, 2004; Yarish and Pereira, 2008; Abreu *et al.*, 2009).

Barrington, *et al.* (2009) have provided an excellent review of the work being done in several parts of the world on the laboratory and commercial-scale demonstration of technologies which apply this concept. A wide variety of genera of with high potential for development in IMTA systems in marine temperate waters include:

- **Seaweeds:** *Laminaria*, *Saccharina*, *Undaria*, *Alaria*, *Ecklonia*, *Lessonia*, *Macrocystis*, *Gigartina*, *Sarcothalia*, *Chondracanthus*, *Callophyllis*, *Gracilaria*, *Gracilariopsis*, *Porphyra*, *Chondrus*, *Palmaria*, *Asparagopsis* and *Ulva*.
- **Molluscs:** *Haliotis*, *Crassostrea*, *Pecten*, *Argopecten*, *Placopecten*, *Mytilus*, *Choromytilus* and *Tapes*.
- **Echinoderms:** *Strongylocentrotus*, *Paracentrotus*, *Psammechinus*, *Loxechinus*, *Cucumaria*, *Holothuria*, *Stichopus*, *Parastichopus*, *Apostichopus* and *Athyonidium*.
- **Polychaetes:** *Nereis*, *Arenicola*, *Glycera* and *Sabella*.
- **Crustaceans:** *Penaeus* and *Homarus*.
- **Fish:** *Salmo*, *Oncorhynchus*, *Scophthalmus*, *Dicentrarchus*, *Gadus*, *Anoplopoma*, *Hippoglossus*, *Melanogrammus*, *Paralichthys*, *Pseudopleuronectes* and *Mugil*.

Selection of species is based on established husbandry practices, habitat/site appropriateness, ecosystem functions, biomitigation ability, economic value and their acceptance by consumers.

The IMTA concept is very flexible in that it can be land-based or open-water, marine or freshwater systems, and may comprise several species combinations

(Chopin, 2006). For example, in Israel, research and development efforts towards land-based integrated aquaculture systems have focused on the combined use of algae and bivalves (with or without the addition of grazers) to treat effluent from land-based aquaculture systems (Shpigel, 2005; Shpigel and Neori, 2007). Three practical approaches of land based IMTA have been developed: 1. Fish-Bivalve-Seaweed (Shpigel *et al.*, 1993; Shpigel and Neori, 1996; Neori *et al.*, 2000). 2. Fish-Seaweed-abalone/sea urchins (Shpigel and Neori, 1996; Neori *et al.*, 1998; Neori *et al.*, 2000; Stuart and Shpigel, 2009) and 3. Fish-Constructed Wetland with *Salicornia* (Stuart and Shpigel, 2009). These authors have demonstrated that land-based systems can be engineered in such a way as to maintain different organisms and processes in separate culture units. Waste from the production of primary organisms becomes a readily available input, allowing for intensification. Optimization of biological processes and adjustment of parameters in the secondary units provides for the effective treatment of effluents for recirculation or before discharge. Emphasis in production may shift from one organism to another according to practical or economical considerations (Shpigel and Neori, 2007; Neori *et al.*, 2007). In Canada, a project has demonstrated the integration of culture of salmon, blue mussels (*Mytilus edulis*) and kelps in an open-water system (Chopin and Robinson, 2004). Innovative kelp culture techniques have been developed and improved both in the laboratory and at the aquaculture sites. Increased growth rates of kelps and mussels cultured in proximity to fish farms, compared to reference sites, reflected the higher food availability and energy. Nutrient, biomass and oxygen levels are being monitored to estimate the biomitigation potential. Salmonid solid and soluble nutrient loading is being modeled as the initial step towards the development of an overall flexible IMTA system. The extrapolation of a mass balance approach using bioenergetics is being juxtaposed with modern measures of ecosystem health. Long-term research is documenting food safety, animal health benefits and consumer acceptance of products from these systems (Barrington *et al.* 2009).

Several research and development strategies have been proposed with the goal of moving these concepts towards widespread commercial implementation (Troell *et al.*, 2003; Barrington *et al.* 2009). These include:

- Study biological, biochemical, hydrographic, oceanographic, seasonal and climatic processes and their interactions for selected site and production system types.
- Conduct R&D at scales relevant to commercial implementation or suitable for extrapolation, while still not being irreversible.
- Develop models to estimate the appropriate biological and economic ratios between fed organisms, organic extractive organisms and inorganic extractive organisms at the aquaculture sites.
- Adapt and develop new technologies to improve operational efficiencies.
- Encourage multidisciplinary input from biologists, engineers, statisticians, economists, farmers and marketing experts in developing design and operations.

- Analyze roles and functions of IMTA systems for improved environmental, economic and social acceptability within the broader perspective of integrated coastal zone management (ICZM) and ecosystem carrying/assimilative capacity.
- Develop and harmonize appropriate animal/plant health and food safety regulatory and policy frameworks to enable more universal development of commercial-scale operations.
- Develop incentive approaches to facilitate outreach and technology transfer of these novel and somewhat complex technologies from scientists to industry, government and the public.

Biofloc technologies

One of the intrinsic features of aquatic ecosystems is the almost complete recycling of feed materials through the biological food web. Fish excretions are metabolized by microorganisms, consumed in turn by different animals and eventually eaten by the fish. Although an essential feature in extensive ponds, cycling of wastes has declined as pond production intensified. Organic loads in more intensive ponds are high, creating extra oxygen demand and settling to the pond bottom as anaerobic sludge where they slow down the bio-recycling sequence, leading to the production of toxic compounds and the buildup of ammonium and nitrite. Trends towards further intensification of aquaculture will continue. Extensive and even semi-intensive production systems demand increasingly limited land and water resources in comparison to more efficient intensive systems (Avnimelech *et al.*, 2008). Furthermore, demands of biosecurity, effluent management, quality control management efficiencies, transparency and profitability drive producers to intensify.

Biofloc systems are based upon integration of the target crop and microbial community within a pond and can be considered as ecosystem management (see Avnimelech, 2009 for review). Water treatment is accomplished within the pond, with no need for a separate water treatment component. A dense microbial community develops when water exchange is limited and organic substrates accumulate. With appropriate aeration and mixing, an aerobic microbial community develops in the water column reaching 10^7 – 10^{10} microbial cells per cm^3 of pond water (Burford *et al.*, 2003; Avnimelech, 2009). Inorganic nitrogen build up is controlled through nitrogen assimilation by adding carbonaceous materials. Under such conditions, microbes take up the ammonium from the water, cycling it to less toxic forms and creating microbial protein. In addition, ammonium and nitrite accumulation are controlled through the development of an efficient nitrifying community in the biofloc system. The bioflocs are micro-environments very rich in organic matter and nutrients embedded within a relatively poor water phase. The bioflocs are made of a wide assemblage of bacteria, algae, protozoa and various zooplankters. Ongoing research is being directed towards achieving a better understanding of the components of this community and methods to manage the assemblage to minimize potential

negative components while maximizing benefits (De Schryver *et al.*, 2008; Ray *et al.*, 2009). A healthy and diverse biofloc community may reduce potential for dominance of pathogenic strains and contribute probiotic effects.

An important feature of biofloc technologies (BFT) is the ability to recycle proteins. The micro-organisms in the water tend to aggregate and form bio-flocs that can be harvested by tilapia, penaeid shrimp and filter-feeders. Protein utilization rises from 15–25 percent in conventional ponds to 45 percent in BFT. Flocs can provide proteins, vitamins and minerals (Tacon *et al.*, 2002). The doubled feed efficiency and nutritional contributions are increasingly important as feed costs rise and pressures on limited resources increase. The elimination of water exchange is an important benefit with potential to enhance environmental sustainability of pond-based culture systems.

Information technology

The increasing pace of innovation and development of information technologies continues to expand the range of general and specialized applications for aquaculture. The applications of information and communication technology for the aquaculture industry are as diverse as the industry itself, ranging from highly specialized feedback and decision-making systems for high technology salmon farming operations to the increasing availability of information and learning resources for small-scale rural farmers. The topic was recently reviewed by Bostock (2009), who provided a detailed review summarizing the use of information technology in aquaculture; the following section provides a summary of this excellent synopsis.

New developments in the application of information technology for monitoring, control and automation are improving the ability of large industrialized production systems to manage crops and improve production efficiencies. Recent trends towards consolidation in some of the more industrialized sectors of aquaculture production have resulted from increasing cost competitiveness and associated demands for reducing production costs. Sensors and monitoring tools are being applied to better control water quality and to better protect against catastrophic loss. These may be individual units tied to a production system or networked centralized systems for monitoring multiple units and multiple sites. New sensors are being developed and marketed for monitoring of the target crops. Coupled with automated feeding systems, these technologies can be applied for counting fish, measuring fish, monitoring mortalities, sensing feeding behaviour and uneaten feed, even down to the monitoring of individual fish using electronic telemetry tags. As these sensors decrease in size and cost, their application may expand beyond highly industrialized salmon farms to wider applications with corresponding opportunities for improving efficiencies and reducing waste, thereby contributing to financial and environmental sustainability.

Computer-based systems for managing stocks and production data, optimizing production schedules, controlling feed purchases and making harvest decisions are becoming more common, even in medium-scale operations. Information and communication technologies are increasingly used to manage the array of complex business processes in a typical medium or large-scale aquaculture operation, with some moving towards integration of major business functions through enterprise resource planning software. Availability of better software tools will improve business planning, allowing future developers to better model everything from potential production dynamics to site section factors, potentially improving the outlook for sustainable project development.

One of the most important areas in which emerging information and communication technologies will contribute to future aquaculture sustainability is in assuring quality and traceability (Bostock, 2009). As the implementation and public acceptance of codes of practice and labeling expands, a corresponding demand is developing for databases, verification records and operational logs for traceability, management and reporting purposes. Technologies that support these efforts are becoming more powerful and cheaper to implement. More sophisticated systems are using real time links between traceability and stock management tools, automated data capture and networking technologies for linking database elements and customizing entry and reporting. With the wide array of traceability and labeling standards that are in effect or under development and the number of companies developing systems to provide tracking, tracing, and management information solutions increasing, future efforts to develop standards and management tools will need to focus on harmonization to reduce inefficiencies and facilitate data transfer.

The expanding role of the Internet is becoming an ever more important tool for remote management of production systems; for connecting with customers for marketing, sales and public relations; and for facilitating research, education and extension. Even the smallest-scale producers will increasingly be able to access better information and training as information technologies improve, availability expands and costs decline. Vast amounts of knowledge are available through the Internet, and the challenge continues to be managing the quality of the information and developing tools to deliver it in formats necessary for the diverse aquaculture communities in need of training. New virtual learning environments and educational tools are being developed, providing improved opportunities to train practitioners and provide extension assistance to growers, from rural cooperatives to mid-level producer groups to remote production facilities within a larger integrated company.

Finally, information technology is providing a fundamental foundation for the process of aquaculture innovation and technology development in and of itself. Better real time communications are linking universities, research laboratories and industry like never before. Research results are being disseminated faster

and faster through electronic outlets, allowing the sharing of innovative advances and faster market implementation. This communication can also serve to focus research and development efforts. As discussion lists, personal networking tools, and partnering tools between cooperatives or companies expand, consensus on looming long-term issues, technology gaps and productivity bottlenecks can be reached. Benchmarks can be developed to track progress in overcoming obstacles or in improving standards. Embracing and enhancing these tools and trends can provide some of the most important opportunities for improving sustainability and productivity of the aquaculture sector.

Conclusions

The pace and scope of technological advances in aquaculture has increased over the decade since the publication of *Aquaculture in the Third Millennium* (NACA/FAO, 2001). Continued advances in genetics, health, nutrition, production systems engineering and information technology have had profound effects on aquaculture production. However, technology development and associated improvements in sustainability and productivity have, in many cases, been implemented for and by large-scale industrial aquaculture production systems. As a large proportion of aquaculture production comes from small farmers, particularly in Asia, increased efforts must be devoted to improving the development of technologies specifically for small and medium-scale systems, as well as extending the availability of existing applicable knowhow and technologies. In many cases this will require better organization of the sector and an investment of resources in expansion of medium-scale entrepreneurial aquafarming businesses where economic returns can drive industry improvement and expansion. Successful examples include the application of diagnostic technologies for regional farmers' associations, use of sex reversal and genetically improved strains of tilapia for local seed production centers, and shifting of production from trash fish and mash feeds to well-formulated pelleted or extruded feeds (FAO, 2010). These types of opportunities can and should be expanded along with classical improvements in management practices to improve productivity, socio-economic benefits and environmental sustainability of small and medium-scale aquaculture.

To focus and track progress in innovation and application of technologies, the scientific community, industry, government and NGOs should work towards consensus on common goals. An example of a consensus-building workshop which prioritized goals for technological innovation in aquaculture can be found in Browdy and Hargreaves (2009). Priority goals may address many areas of importance to future aquaculture development including: i) improving productivity and financial sustainability to encourage entrepreneurship and industry expansion; ii) increasing environmental responsibility, preparing for climate change effects and improving resource utilization efficiencies; and iii) raising socio-economic benefits to communities and improving food security.

Once goals are set, a series of criteria and quantitative metrics should be developed to focus research efforts and evaluate progress, outcomes and impacts for each objective. For example, use of pedigrees coupled with heritability metrics allows the tracking of performance improvements in traits of interest for selective breeding programmes. In developing feeds and feeding programmes, metrics focusing on efficiency can have a huge impact on financial success, as well as environmental sustainability. These could include improving feed conversion efficiencies or tracking “fish in fish out” (FIFO) ratios to quantify the amount of fish from capture fisheries necessary to produce a unit of cultured fish. A third example could be the evaluation of carbon, nutrient or energy inputs for production of a kilogram of fish to provide focus on energy usage and carbon/nutrient footprints. In many cases, improved application of technologies can contribute to environmental stewardship and efficient resource utilization while concurrently improving economic opportunities and returns. This review provides numerous examples of these types of potential win/win opportunities that can arise from focused research and development efforts. As costs of technologies drop, communication and information technologies expand and the pace of innovation increases, new and expanding opportunities will continue to emerge for the expansion of sustainable aquaculture production to meet world food needs.

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Aquaculture feeds: addressing the long-term sustainability of the sector

Expert Panel Review 1.3

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Abstract

It is estimated that about 29 million tonnes of farmed fish and crustaceans (44.5 percent of the total global aquaculture production in 2007) is dependent upon the supply of external nutrient inputs provided in the form of fresh feed items, farm-made feeds or commercially manufactured feeds. Total industrial compound aquafeed production has increased over three-fold from 7.6 million tonnes in 1995 to 27.1 million tonnes in 2007, with production growing at an average annual rate of 11.1 percent. Aquafeed production is expected to

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continue growing at a similar rate to 70.9 million tonnes by 2020. Although current estimates for industrially produced aquafeed for the period 2007–2010 vary between 24.4 and 28.9 million tonnes, aquafeed volume represents only 4 percent of total global animal feed production of over 708 million tonnes in 2009. In contrast to compound aquaculture feeds, there is no comprehensive information on the global production of farm-made aquafeeds (estimated at between 18.7 and 30.7 million tonnes in 2006) and/or on the use of low-value trash fish or forage fish species as feed, with current estimates for China in 2008 ranging between 6 and 8 million tonnes.

Feed-fed aquaculture production, and in particular the production of higher-trophic-level finfish and crustaceans (e.g. shrimp, salmonids, marine finfish, eels) is largely dependent upon capture fisheries for major dietary sources of protein and lipid. For example, in 2007 the aquaculture sector is estimated to have consumed 3.84 million tonnes of fishmeal (or 68.4 percent of global production) and 0.82 million tonnes of fish oil (or 81.3 percent of global production for that year). However, despite the continued dependence of aquaculture production upon the use of fishmeal and fish oil, there is wide variation in fishmeal and fish oil usage between major producing countries for individual farmed species.

It is estimated that the total usage of terrestrial animal by-product meals and oils within compound aquafeeds ranges between 0.15 and 0.30 million tonnes, or less than 1 percent of total global compound aquafeed production – clearly there is considerable room for increased usage. Among plant feed ingredients, soybean meal is currently the commonest protein source used in compound aquafeeds. Based on total compound aquafeed production of 27.1 million tonnes, it is estimated that the aquaculture feed sector consumed about 6.8 million tonnes of soybean meal (25.1 percent of total compound aquafeeds by weight) in 2007. Other plant proteins that are being increasingly used include corn products, pulses, oilseed meals and protein from other cereal products.

Alternative lipid sources to fish oil are being used in greater amounts. Key alternatives include vegetable oils (preferably those with high omega-3 content) and poultry oil. The use of oil from farmed fish offal is also a potential omega-3 source for other farmed fish. The production of marine microalgae or bacteria with very high content of highly unsaturated fatty acids (HUFA) is currently expensive for use in most aquaculture feeds but as production methods become more cost-efficient, the situation is likely to change.

Prices for food and feed ingredients are likely to continue to increase due to increasing demands from the increasing population, diversion of some grains for use in biofuels, increasing costs of production and transport, and changes in global trade. The focus on carbohydrate-rich fractions for production of biofuels may provide an opportunity to use protein fractions for feed ingredients.

Although the current discussion about the use of marine products as aquafeed ingredients focuses on fishmeal and fish oil resources, the sustainability of the aquaculture sector is more likely to be linked with the sustained supply of terrestrial animal and plant proteins, oils and carbohydrate sources for aquafeeds, particularly so because a significant proportion of aquaculture production is of non-carnivorous species. Therefore, aquaculture-producing countries should place more emphasis on maximizing the use of locally available feed-grade ingredient sources and move away from the use of potential food-grade feed resources.

KEY WORDS: *Aquaculture, Feeds, Development, Global trends, Sustainable aquaculture.*

Introduction

Aquaculture's dramatic rise and emergence as a major provider of much needed aquatic food for the global market has been possible because of a combination of factors that include:

- the recognition of aquaculture as a viable economic activity and source of livelihood;
- the provision of an enabling legislative framework for conducting the activity;
- the availability of suitable land and water resources and technical know-how for conducting farming operations; and
- in the case of most fish and crustacean farming operations, the availability of nutrient inputs in the form of fertilizers and/or feed.

If finfish and crustacean aquaculture is to maintain its current average growth rate of 8 to 10 percent per year to 2025, the availability of nutrient and feed inputs will have to grow at a similar rate. However, while this may have been easily attainable in the past when most aquaculture industries relying on external nutrient inputs were still in their infancy, it will present a much greater challenge as the sector matures and grows into a major consumer and competitor for feed resources. This paper will consider dietary feeds and feeding regimes based on the external provision of fresh feeds (usually fed singly) and farm-made feeds and commercial feeds composed of mixtures of different feed ingredients.

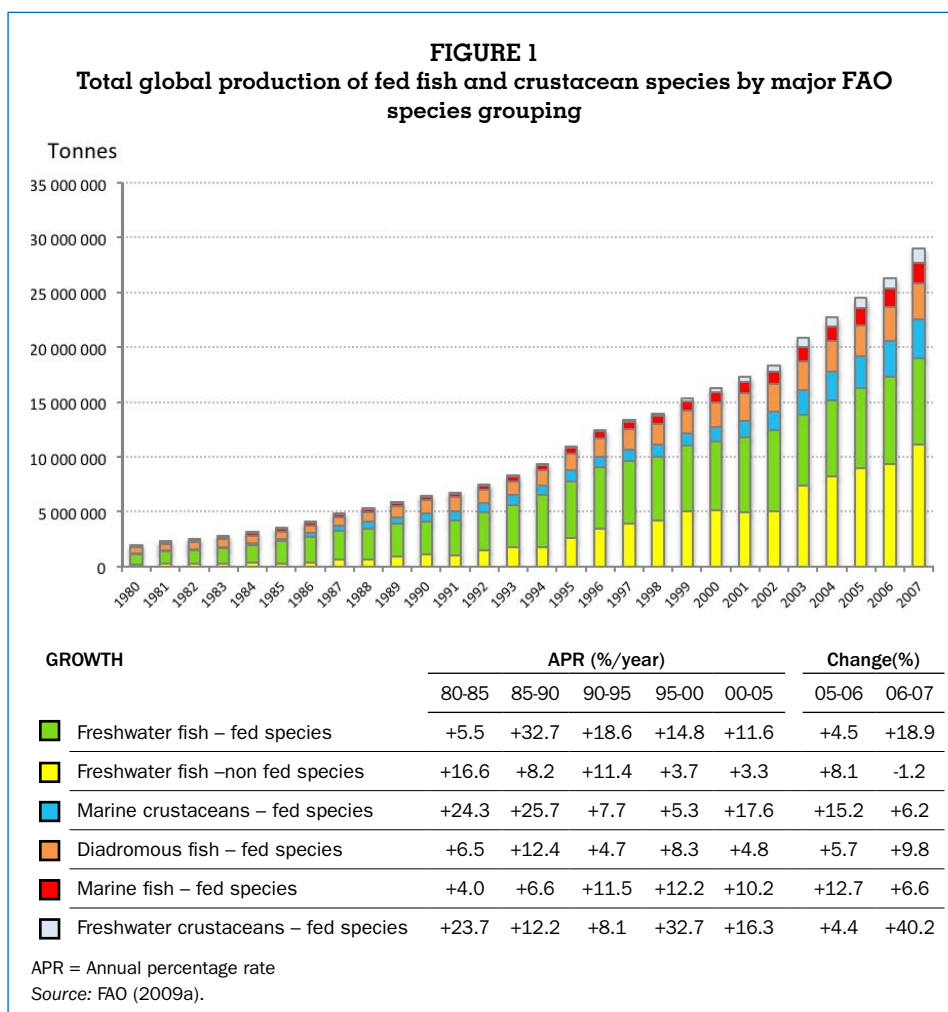
Current feeds and feeding practices

Major fed fish and crustacean species

About 29 million tonnes of farmed fish and crustaceans, or 44.5 percent of the total global production of farmed aquatic animals and plants, is currently dependent upon the supply of nutrient inputs in the form of externally provided fresh feed items, farm-made feeds or commercial pelleted feeds. The above estimate excludes filter-feeding fish species (e.g. silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*): total production 5.8 million tonnes in

2007) and freshwater fish production not reported down to the species level (2.0 million tonnes in 2007; FAO, 2009a). Moreover, of the more than 200 species of fish and crustaceans currently believed to be fed on externally supplied feeds, eight species account for 60 percent of total global fed species production: grass carp (*Ctenopharyngodon idellus*), common carp (*Cyprinus carpio*), whiteleg shrimp (*Litopenaeus vannamei*), catla (*Catla catla*), Nile tilapia (*Oreochromis niloticus*), Crucian carp (*Carassius carassius*), Atlantic salmon (*Salmo salar*), and pangassid catfishes (striped/tra catfish [*Pangasianodon hypophthalmus*] and basa catfish [*Pangasius bocourti*]), (FAO, 2009a). In this respect aquaculture is similar to agriculture; global livestock production is concentrated in a handful of major species like pig, chicken, cattle, sheep, turkey, goat, duck and buffalo (FAO, 2009b).

Figure 1 shows the total global production of fed fish and crustaceans by major species grouping, together with their respective growth at five-year intervals from



1990 to 2007. In marked contrast to capture fisheries, freshwater fish species dominate finfish aquaculture production (Tacon *et al.*, 2010), with over 78.6 percent of fed finfish production being freshwater species in 2007 (FAO, 2009a).

Of particular note are the high double-digit growth rates of all major groupings during the 1980s and 1990s, with the overall growth of fed fish and crustacean aquaculture production stabilizing to an average of 10.5 percent per year by 2007. In contrast, livestock meat production and capture fisheries production have grown at an average percent rate of 2.5 percent and 1 percent per year since 1980, respectively (FAO, 2009b).

The major fed fish and crustacean species groups can be ranked in order of total global production by weight in 2007 as follows:

Freshwater fed fish (18.82 million tonnes, valued at USD23.4 billion)

- Carps – 12.98 million tonnes, 9 major species
- Tilapias – 2.50 million tonnes, 2 major species
- Catfishes – 2.27 million tonnes, 5 major species
- Miscellaneous freshwater fish species – 1.06 million tonnes, 6 major species

Marine fed crustaceans (3.51 million tonnes, valued at USD14.0 billion)

- Shrimp – 3.27 million tonnes, 6 major species
- Crabs – 231 000 tonnes, 1 major species

Diadromous fed fish (3.26 million tonnes, valued at \$ 13.3 billion)

- Salmon – 1.56 million tonnes, 2 major species
- Trout – 694 000 tonnes, 1 major species
- Milkfish – 667 000 tonnes, 1 major species
- Eels – 274 000 tonnes, 1 major species
- Miscellaneous diadromous fish species – 63 000 tonnes, 1 major species

Marine fed fish (1.85 million tonnes, valued at USD6.4 billion)

- Seabass – 365 000 tonnes, 2 major species
- Mulletts – 272 000 tonnes, 1 major species
- Porgies, seabreams – 263 000 tonnes, 2 major species
- Jacks, trevalles – 176 000 tonnes, 1 major species
- Flounders, halibuts, soles – 126 000 tonnes, 1 major species
- Croakers, drums – 115 000 tonnes, 2 major species
- Groupers – 75 000 tonnes
- Miscellaneous marine fish species – 436 000 tonnes, 2 major species

Freshwater crustaceans (1.34 million tonnes, valued at USD6.0 billion)

- Crabs – 489 000 tonnes, 1 major species
- Crawfish, crayfish – 318 000 tonnes, 1 major species
- River prawns – 451 000 tonnes, 2 major species

The fastest-growing major fed species groups over the last decade (2000 to 2007) have been catfish (average rate of 23.1 percent), freshwater crustaceans (17.6 percent), shrimp (16.4 percent), tilapia (11.2 percent) and marine fish (10.0 percent). This contrasts with the reduced growth of salmon (6.2 percent), milkfish (5.2 percent), trout (4.4 percent), fed carps (3.8 percent) and eels (3.7 percent) over the same period (FAO, 2009a).

In-country fed species production and feeding practices

On a global basis, over 84.6 percent of fed fish and crustacean aquaculture production was produced on the Asian continent in 2007 (24.5 million tonnes), followed by the Americas (2.0 million tonnes or 6.8 percent), Europe (1.6 million tonnes or 5.5 percent), Africa (0.82 million tonnes or 2.8 percent) and Oceania (45 418 tonnes or 0.15 percent) (FAO, 2009a). Twenty countries accounted for 94 percent of total global fed fish and crustacean production in 2007, with China alone accounting for over half the global total (Table 1).

It follows therefore from the above that these countries will also be the large producers and consumers of feed, either in the form of commercial feeds, farm-made feeds or fresh feeds.

TABLE 1

The top 20 country producers of fed fish and crustaceans in 2007

Country	Production (million tonnes) (% total)
China	15.10 (52.1)
India	2.89 (10.0)
Indonesia	1.36 (4.7)
Viet Nam	1.30 (4.5)
Thailand	1.02 (3.5)
Norway	0.83 (2.8)
Philippines	0.67 (2.3)
Chile	0.66 (2.3)
Egypt	0.64 (2.2)
Bangladesh	0.60 (2.1)
United States of America	0.37 (1.3)
Japan	0.30 (1.0)
Brazil	0.27 (0.9)
Myanmar	0.26
Taiwan Province of China	0.23
Ecuador	0.17
Mexico	0.15
United Kingdom	0.15
Turkey	0.14
Pakistan	0.13

Source: FISHSTAT (FAO, 2009a).

Fed carps

Fed carps (Chinese carps, Indian major carps, other cyprinids) represent the largest fed species group, with the sector growing at an average rate of 3.8 percent per year over the last decade (FAO, 2009a). It is estimated that the amount of carp that is fed, as a percentage of total carp production (excluding Indian major carps), has increased from 20 percent in 1995 to 48 percent in 2007 (Tacon and Metian, 2008a). Total global commercial carp feed production has increased from 2.1 to 8.2 million tonnes from 1995 to 2007 and is projected to reach 14.8 million tonnes by 2020. In contrast, almost all Indian major carp production is still based on the use of low-cost locally produced farm-made feeds (Ayyappan and Ahamad Ali, 2007), with fresh feed items still only being fed to Chinese carps (primarily grass carp), depending upon the financial resources of the farmer (Barman and Karim, 2007; Weimin and Mengqing, 2007).

Of particular note is the difference in the estimated farm gate unit value of the same species between producing countries, depending upon individual market preferences. For example, grass carp has a minimum reported unit value of USD0.96/kg in China and a maximum reported unit value of USD3.0/kg in Iran (FAO, 2009a), the latter higher market values presumably also allowing the use of more costly farm production methods and feeding methods, if so required.

Tilapias

Tilapias represent the second largest freshwater fish fed species group, with the sector growing at an average rate of 11.2 percent per year over the last decade (FAO, 2009a). It is estimated that the percent of total tilapia production fed on commercial feeds has increased from 70 percent in 1995 to 82 percent in 2007 (Tacon and Metian, 2008a). Total global commercial tilapia feed production increased from 1.0 to 3.5 million tonnes from 1995 to 2007 and is expected to reach 12.0 million tonnes by 2020.

Catfishes

Catfishes represent the third largest freshwater fish fed species group, with the sector growing at a very high rate of 23.1 percent per year over the last decade (FAO, 2009a). It is estimated that about 72 percent of the global catfish were fed commercial feeds in 2007 (Tacon and Metian, 2008a). Commercial catfish feed production increased from 587 000 tonnes in 1995 to 2.4 million tonnes in 2007 and is projected to reach 11.7 million tonnes by 2020.

Miscellaneous freshwater fishes

These represent the fourth largest freshwater fish fed species group, with the sector growing at a high rate of 21.1 percent per year over the last decade (FAO, 2009a). It is estimated that about 17 percent of miscellaneous freshwater fish that are fed received commercial feeds in 2007 (Tacon and Metian, 2008a). Commercial feed production increased from 15 000 tonnes in 1995 to 359 000

tonnes in 2007 and is expected to reach 2.8 million tonnes by 2020. With the exception of omnivorous/herbivorous species (e.g. pirapatinga (*Piaractus brachypomus*), cachama (*Colossoma macropomum*)), most of the fishes within this species group are highly piscivorous and are still usually fed on live/trash fish feed items (Chen *et al.*, 2007; De Silva and Phillips, 2007; Weimin and Mengqing, 2007).

Salmon

Salmon represent the largest diadromous fish species group, with the sector growing at an average rate of 6.2 percent per year over the last decade (FAO, 2009a). It is estimated that 100 percent of total salmon aquaculture production is fed on commercial feeds. Total global commercial salmon feed production increased from 806 000 tonnes in 1995 to 2.0 million tonnes in 2007 and is projected to reach 3.8 million tonnes by 2020.

Trout

Trout represent the second largest diadromous fish species group, with the sector growing at an average rate of 4.4 percent per year over the last decade (FAO, 2009a). It is estimated that 100 percent of total trout aquaculture production is fed on commercial feeds. Total global commercial trout feed production increased from 588 000 tonnes in 1995 to 902 000 tonnes in 2007 and is expected to reach 1.7 million tonnes by 2020.

Milkfish

Milkfish represent the third largest diadromous aquaculture species, with production growing at an average rate of 5.2 percent per year over the last decade (FAO, 2009a). It is estimated that the amount of milkfish fed on commercial feeds, as a percentage of total production, increased from 30 percent in 1995 to 41 percent in 2007 (Tacon and Metian, 2008a). Total global commercial milkfish feed production increased from 220 000 tonnes in 1995 to 547 000 tonnes in 2007 and is expected to reach 1.1 million tonnes by 2020.

Eels

Eels represent the fourth largest diadromous aquaculture species group, with production growing at an average rate of 3.7 percent per year over the last decade (FAO, 2009a). It is estimated that the amount of eels fed on commercial feeds, as a percentage of total production, increased from 90 percent in 1995 to 95 percent in 2007 (Tacon and Metian, 2008a). Total global commercial eel feed production increased from 338 000 tonnes in 1995 to 416 000 tonnes in 2007 and is projected to reach 595 000 tonnes by 2020.

Marine fish

Marine fish represent the last major fish species group, with production growing at an average rate of 10.0 percent per year over the last decade (FAO, 2009a). It is estimated that total marine fish production fed on commercial feeds, as a

percentage of total production, increased from 50 percent in 1995 to 72 percent in 2007 (Tacon and Metian, 2008a). Total global commercial marine fish feed production increased from 533 000 tonnes in 1995 to 2.5 million tonnes in 2007 and is expected to reach 7.6 million tonnes by 2020.

At present, the bulk of marine finfish cage aquaculture production in China is still using lower-cost fresh feeds based on small-sized pelagic fish species in the form of fresh/frozen fish (Chen *et al.*, 2007; Weimin and Mengqing, 2007). China alone reportedly consumed between 4 and 5 million tonnes of lower-value pelagic fish as aquaculture feed in 2005.¹

Shrimp

Shrimp represent the largest crustacean species group, with species group production growing at an average rate of 16.4 percent per year over the last decade (FAO, 2009a). It is estimated that the amount of shrimp fed on commercial feeds, as a percentage of total production, increased from 75 percent in 1995 to 93 percent in 2007 (Tacon and Metian, 2008a). Total global commercial shrimp feed production increased from 1.4 million tonnes in 1995 to 4.8 million tonnes in 2007 and is projected to reach 12.0 million tonnes by 2020.

Freshwater crustaceans

Freshwater crustaceans represent the second largest crustacean species group, with group production growing at an average rate of 17.6 percent per year over the last decade (FAO, 2009a). It is estimated that the amount of freshwater crustaceans fed on commercial feeds, as a percentage of total production, increased from 35 percent in 1995 to 47 percent in 2007 (Tacon and Metian, 2008a). Total global commercial freshwater crustacean feed production increased from 91 000 tonnes in 1995 to 1.3 million tonnes in 2007 and is expected to reach 2.7 million tonnes by 2020.

Global aquaculture feed production by major species group and country

On the basis of the above information, it is estimated that the total global production of commercial aquaculture feeds was 27.1 million tonnes in 2007, including:

- Carp feeds (8.2 million tonnes or 30.4 percent)
- Shrimp feeds (4.8 million tonnes or 17.8 percent)
- Tilapia feeds (3.5 million tonnes or 12.9 percent)
- Marine fish feeds (2.5 million tonnes or 9.3 percent)
- Catfish feeds (2.4 million tonnes or 9.0 percent)
- Salmon feeds (2.0 million tonnes or 7.5 percent)
- Freshwater crustacean feeds (1.3 million tonnes or 4.9 percent)

¹ Source: Paper presented by W. Jin on *Fishmeal as a dietary ingredient in China – first impressions*. International Fishmeal and Fish Oil Organization 2006 Annual Conference, October 23–26, 2006, Barcelona, Spain.

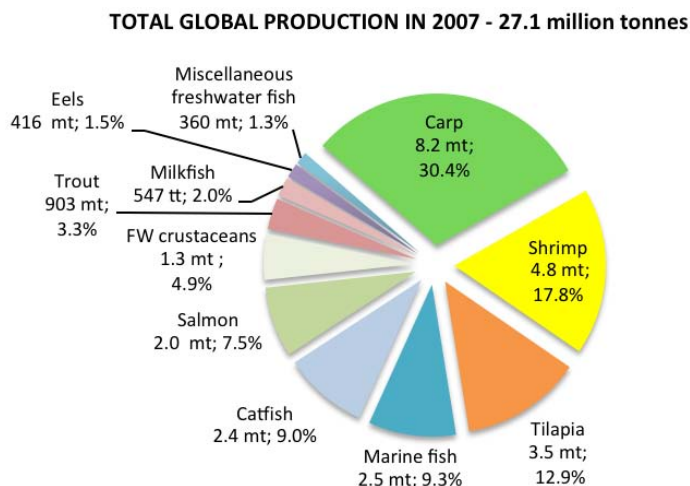
- Trout feeds (902 000 tonnes or 3.3 percent)
- Milkfish feeds (547 000 tonnes or 2.0 percent)
- Eel feeds (416 1000 tonnes or 1.5 percent)
- Miscellaneous freshwater fishes (359 000 tonnes or 1.3 percent)

The above estimate represents a 6.8 percent increase in production from the total estimated commercial aquaculture feed production of 23.4 million tonnes in 2006 (Gill, 2007; Tacon and Metian, 2008a). The commercial aquaculture feed sector has grown over three-fold from 7.6 to 27.1 million tonnes from 1995 to 2007 (average annual rate of 11.1 percent since 1995; Figure 2), and is expected to continue growing at a similar rate over the next decade to 70.9 million tonnes by 2020.

In some countries where the aquaculture sector has been growing very rapidly, there has been a similar rapid production of commercial aquafeeds (e.g. in Viet Nam, official figures show that aquafeed production increased from 336 000 tonnes in 1999 to 762 000 tonnes in 2004, with production more than doubling again to 1 863 000 tonnes in 2008, and estimated at 2.4 million tonnes in 2009, an increase in production of over 700 percent in a decade (Best, 2010a).

Table 2 shows the major country producers of commercial aquafeeds. The results are based on the individual country responses received to an electronic survey conducted for this review. The results show an estimated total

FIGURE 2
Estimated global production of commercial aquaculture feeds by major species grouping in 2007 (values in thousand (tt) or million (mt) tonnes and as percent of total)



Source: Data taken from table above.

production of between 24.7 and 29.1 million tonnes of commercial aquafeeds in the period 2007–2010, in line with the estimates given above for major aquaculture species.

TABLE 2
Major country producers of commercial aquaculture feeds, 2007–2010

Country	Commercial aquaculture feed production estimate (tonnes)
China (2008)	13 000 000 – 15 000 000
Viet Nam (2008/2009)	1 625 000 – 2 800 000
Thailand (2008/2009)	1 210 327 – 1 445 829
Norway (2008/2010)	1 136 800 – 1 382 000
Indonesia (2008/2009)	1 030 000 – 1 184 500
Chile (2008)	883 305 – 1 050 000
United States of America (2008)	700 000 – 750 000
Japan (2008)	500 000
India (2008/2009)	500 000
Philippines (2007)	400 000 – 450 000
Taiwan Province of China (2007)	345 054
Brazil (2008)	324 000
Egypt (2008)	310 000
Mexico (2008/2009)	222 800 – 282 500
Greece (2009)	262 000
Ecuador (2009)	235 000
Malaysia (2009)	226,000
United Kingdom (2008)	212 900
Turkey (2009)	170 000
Canada (2008)	161 600
Peru (2008)	145 000
Korea Rep. (2008)	126 898
Bangladesh (2007)	100 000 – 150 000
Myanmar (2007)	100 000 – 150 000
Russian Federation (2007)	100 000 – 150 000
Colombia (2009)	100 000 – 120 000
Honduras (2007)	75 000 – 100 000
Spain (2007)	75 000 – 100 000
Italy (2007)	68 750
Australia (2008/2009)	58 125
Iran (2007)	50 000 – 100 000
France (2009)	44 400
Denmark (2008)	43 500
Venezuela (2008)	37 580
Germany (2007)	32 000
Nicaragua (2009)	25 508
Costa Rica (2007)	25 000 – 35 000
Nigeria (2007)	20 000 – 30 000
Ireland (2009)	20 000
Argentina (2008)	3 901
Total	24 700 000 – 29 100 000

Source: Tacon, Hasan and Metian (2011).

At present, no precise statistical information exists concerning the total global production of farm-made aquafeeds (Tacon and Hasan, 2007), although production in 2006 has been tentatively estimated to be between 18.7 and 30.7 million tonnes (Tacon, 2008). This figure is in general agreement with total farm-made aquafeed production in Asia, which was reported at 19.3 million tonnes in 2004 (De Silva and Hasan, 2007). As expected, the largest farm-made aquafeed producers in 2006 were all countries from the Asian region and included China (10 to 20 million tonnes), India (6.5 to 7.5 million tonnes), Viet Nam (1 to 1.5 million tonnes), Japan (650 000 to 800 000 tonnes), and Thailand (700 000 to 750 000 tonnes) (Tacon and Metian, 2008a). According to Chinese researchers, farm-made feed production data are not available (Weimin and Mengqing, 2007), although they estimated that farm-made feeds account for about 40 percent of the country's aquaculture production, natural feeds for about 50 percent and commercial feeds for only 10 percent. The same authors stated that 40 to 55 percent of farmed fish production in China is probably fed industrially compounded aquafeeds during the on-growing part of their rearing cycle. These assumptions are similar to that of W. Jin, who estimated that only 20 percent of the aquatic animals that need to be fed on feed in China are fed formulated feeds.² Clearly, more detailed studies and information are required concerning the use of feedfish in China and the extent and status of the on-farm and commercial aquafeed manufacturing sector.

The current widespread use of low-value fish (previously called trash fish) as wet or moist feeds in the Asian region, particularly for the higher-value carnivorous marine fish and crustacean species, is very similar to the situation in the salmon farming industry when it started in Norway in the early 1970s (Talbot and Rosenlund, 2002). The first farmed Atlantic salmon were fed raw fish in the 1970s. The industry progressed to the development of semi-moist and dry pelleted feeds in the 1980s, and to the use of high-energy extruded pelleted feeds in the 1990s and 2000s. Of particular importance is the fact that as a result of these feed technology advancements (see Kearns, 2005; Larraín, Leyton and Almendras, 2005) fish growth and productivity have increased and fish production costs and feed conversion ratios (FCRs) have decreased.

Notwithstanding the above, it is important to highlight the important role played by farm-made aquafeeds, particularly in the production of lower-value (in marketing terms) freshwater fish species for small-scale farmers in countries of South and Southeast Asia and sub-Saharan Africa (Tacon and Hasan, 2007). Farm-made aquafeeds represented over 97 percent of the total carp feeds used by farmers in India (7.5 million tonnes in 2006/2007; Syed Ahamad Ali, Central Institute of Brackishwater Aquaculture, Chennai, India, personal communication, 2009) and still provide the mainstay of feed inputs within many Asian (De Silva

² Source: Paper presented by W. Jin on *Fishmeal as a dietary ingredient in China – first impressions*. International Fishmeal and Fish Oil Organization 2006 Annual Conference, October 23–26, 2006, Barcelona, Spain.

and Hasan, 2007; Ng, Soe and Phone, 2007) and sub-Saharan countries (Hecht, 2007).

Moreover, despite the lack of official published information concerning the direct use of low-value fish and other small pelagic fish species as aquaculture feed, it is estimated that the total use in aquaculture was between 5.6 and 8.8 million tonnes in 2006 (mean of 7.2 million tonnes; Tacon and Metian, 2009a); China alone reportedly consumed 4 to 5 million tonnes in 2005 (see footnote 2). However, estimates for 2008 concerning the direct use of low-value fish as feed in China are currently between 6 to 8 million tonnes; 4–5 million tonnes of marine trash fish and 2–3 tonnes of freshwater fish, including live food fish (approximately 70 percent of this being used for feeding inland carnivorous aquaculture species, and the remainder for marine finfish; Miao Weimin, personal communication, FAO, Bangkok, 2009).

Feed ingredient production and availability

The global production and market availability of feed ingredient sources commonly used in aquaculture feeds has been reviewed by Hasan *et al.* (2007). The review focuses on developing countries; these countries accounted for over 91.5 percent of total fed fish and crustacean production in 2007 (FAO, 2009a). In particular, the review by Hasan *et al.* (2007) includes a global overview (Tacon and Hasan, 2007), regional reviews covering Asia (De Silva and Hasan, 2007), Latin America (Flores-Nava, 2007) and sub-Saharan Africa (Hecht, 2007), and 13 individual country profiles (i.e. Bangladesh, Cameroon, China, Egypt, India, Indonesia, Kenya, Malawi, Nigeria, Philippines, Viet Nam, Thailand and Uganda) concerning aquaculture feed production and ingredient usage.

For the purposes of this paper, feed ingredients can be categorized as follows: (i) animal nutrient sources, (ii) plant nutrient sources and (iii) microbial nutrient sources.

Animal nutrient sources

Aquatic animal protein meals and lipids

The major aquatic animal protein meals and lipids available in the market place can be listed as follows (in order of global production and current market availability):

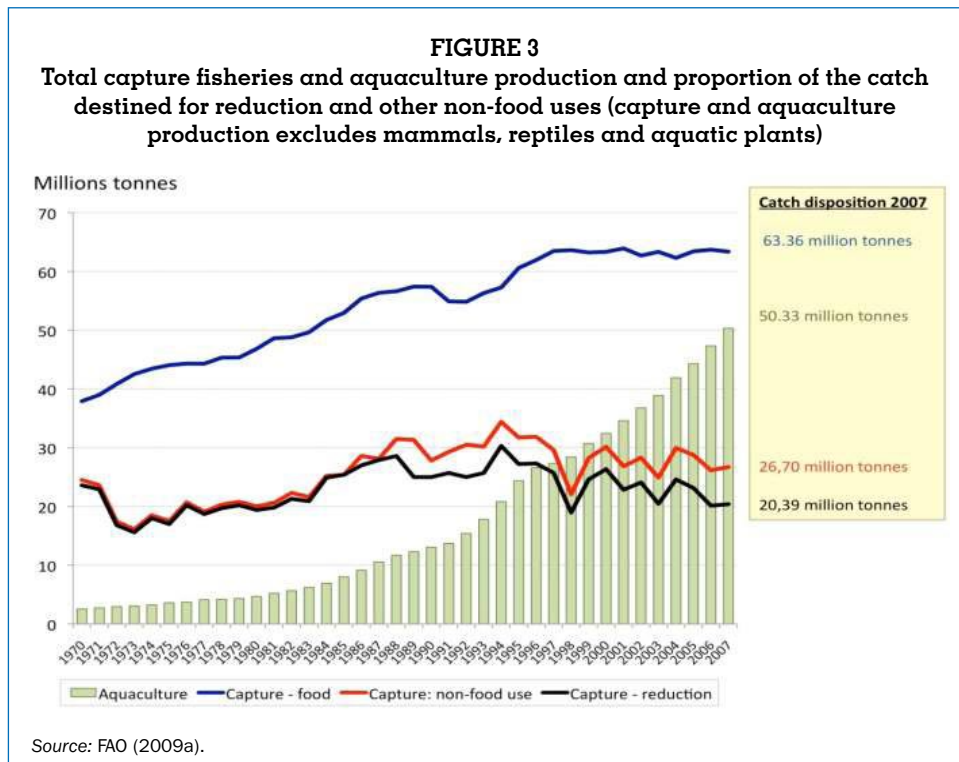
- *Fish/shellfish meals and oils*: produced from wild-harvested whole fish and macro-invertebrate animals, including by-catch.
- *Fish/shellfish by-product meals and oils*: produced from seafood and/or aquaculture processing waste.
- *Zooplankton meals and oils*: produced from wild harvested marine invertebrates.
- *Fish/shellfish hydrolysates, silages and fermentation products*: produced from harvested whole fish, macro-invertebrates, zooplankton and/or seafood processing wastes.

- *Marine polychaete meals*: produced from wild-harvested and/or cultured annelid worms.

Fish/shellfish meals and oils from wild fisheries

Fishmeals and oils derived from wild-harvested whole fish currently constitute the major aquatic protein and lipid source available within the animal feed market place. Despite the growth of the aquaculture sector, the proportion of the global fisheries catch destined for reduction into fishmeal and fish oil has remained relatively static (20.4 million tonnes in 2007; Figure 3), with modest reductions in global fishmeal and fish oil production (1.7 percent per year and 2.6 percent per year since 1995, respectively).

Predictions suggest that total volumes of fishmeal and fish oil from all sources are likely to remain at around 5 million and 1 million tonnes, respectively (except in El Niño years, when volumes are expected to be reduced). Indeed with the increasing demand for the whole fish to go for direct human consumption and with no new fisheries sources to be exploited, there is the likelihood that volumes of fishmeal and fish oil from whole fish will decrease. This reduction might be partially offset by increased volumes of meals and oils from processing by-products (see next section), but the overall trend is likely to be downward.



As with production, the largest exporter of fishmeal and fish oil in 2007 was Peru, exporting 41 percent and 30.6 percent of total world fishmeal and fish oil exports, respectively (FAO, 2009a). However, as for total global production, fishmeal and fish oil exports decreased at an average annual rate of 3.1 percent and 0.7 percent from 1995, respectively (FAO, 2009a). Fishmeal and fish oil imports continue to be dominated by China and Norway, who imported 29.6 percent (969 832 tonnes) and 25.8 percent (231 264 tonnes) of total fishmeal and fish oil imports in 2007, respectively. Moreover, in line with global production and exports, the quantity of fishmeal and fish oil available for export decreased at average annual rates of 2.8 percent and 1.8 percent since 1995, respectively (FAO, 2009a). However, recent data suggest that China's consumption continues to increase, with fishmeal imports increasing to 1 348 676 tonnes in 2008 (Peru 65.0 percent, Chile 17.7 percent, United States of America 5.7 percent), and 1 225 295 tonnes for the first ten months of 2009 (Peru 58.7 percent, Chile 26.0 percent, United States of America 5.5 percent) (Beckman, Wu and Han, 2009).

Fish/shellfish by-product meals and oils

At present, no statistical information is available from the Food and Agriculture Organization of the United Nations (FAO) concerning the total global production of fishmeals and oils produced from seafood and/or aquaculture processing waste. Despite this, it has been estimated that about 6 million tonnes of trimmings and rejects from food fish are currently used for fishmeal and fish oil production (SEAFISH, 2009a). For example, according to SEAFISH (2009b), 38 percent of the fishmeal consumed in the United Kingdom (UK) was produced from trimmings in 2008 (trade estimates). The same authors quoted 2006 trade estimates that 33 percent of the fishmeal produced within the European Union (EU) was manufactured from trimmings/offal from food fish processing plants, and that globally, this figure was about 24 percent. Similarly, the International Fishmeal and Fish Oil Organisation (IFFO) now estimates that about 25 percent of the total global production of fishmeal is being derived from fisheries by-products (Jackson, 2009).

In the case of fishmeals and oils produced from aquaculture processing wastes, it has been estimated that in Chile the production of 600 000 tonnes of salmon yielded 270 000 tonnes of processing waste and farm mortalities, which in turn resulted in the production of 48 600 tonnes of salmon oil and 43 200 tonnes of salmon meal (Anon, 2006).

Zooplankton meals and oils

Major marine zooplankton species which have potential and/or have been considered for use as feed ingredients include the Arctic amphipod *Themisto libellula*, the copepod *Calanus finmarchicus* and the Antarctic krill, *Euphausia superba*. Of these, commercial operations currently only exist for the Antarctic krill, where total landings were reported as 118 124 tonnes in 2007 (FAO,

2009a). As with other shrimp and crustacean meals, no information is currently available concerning the total global production and market availability of krill meal and krill oil. Despite this, krill meal and krill oil are available in the market place (see, for example, www.akerbiomarine.com; www.aquaticceco.com/subcategories/1148/Krill-Meal).

Others

At present, little or no information is available concerning the global production and market availability of fish/shellfish hydrolysates, silages and fermentation products, or concerning the production of wild-harvested and/or cultured marine polychaete worms. However, numerous fish hydrolysates, fermentation products and wild-harvested/cultured polychaetes are currently available in the market place (for example, salmon protein hydrolysate – www.rossyew.co.uk/salmon_pro.htm; farmed polychaetes and polychaete products – www.dragonfeeds.com).

Land animal protein meals and fats

The major land animal protein meals and lipids available in the market place can be listed as follows (in order of global production and current market availability):

- *Meat by-product meals and fats*: produced from slaughtered farmed livestock (cattle, pig, sheep, etc.), and includes meat and bone meal, meat meal, meat solubles and lard/tallow.
- *Poultry by-product meals and fats*: produced from slaughtered farmed poultry, and includes poultry by-product meal, turkey meal, feather meal, chick hatchery waste and poultry fat.
- *Blood by-product meals*: produced from slaughtered farmed livestock (ruminant and monogastric), and includes blood meal, haemoglobin meal and dried plasma products.
- *Miscellaneous invertebrate terrestrial products*: produced from wild-harvested and/or cultured annelid worms, insect larvae/pupae, gastropods (e.g. golden apple snail).

Although no published statistical information exists concerning the individual global production of the above-listed animal by-product meals, it has been estimated that the global combined production of rendered animal protein meals and fats in 2008 was about 13.0 and 10.2 million tonnes, respectively,³ global production of these animal protein meals being over twice that reported for fishmeal in 2008. At present, these terrestrial animal protein meals and fats represent the largest source of animal protein and fats available to the animal feed compounder.

The largest reported producer of rendered animal protein meals and fats in 2008 was the United States of America at 4 094 237 tonnes and 4 576 429 tonnes,

³ Source: Presentation by K. Swisher on *U.S. industry review*. 76th Annual Convention of the National Renderers Association, San Francisco, USA, October 23, 2009.

respectively, followed by the European Union-27 at 3 870 000 tonnes and 2 687 000 tonnes, South America at 3 970 578 tonnes and 2 278 379 tonnes, Australia at 650 000 tonnes and 470 000 tonnes, New Zealand at 214 300 tonnes and 140 000 tonnes, and Turkey at 185 600 tonnes and 84 179 tonnes, respectively (see footnote 3). Clearly, however, these global estimates are low, as they currently exclude most Asian countries from the analysis.

Total exports of rendered animal protein meals was 1 338 954 tonnes in 2008 or 10.3 percent of total global production. The largest reported country exporters were the EU-27 (340 153 tonnes), followed by the United States of America (298 257 tonnes), Australia (259 903 tonnes), New Zealand (149 405 tonnes), Argentina (73 309 tonnes), Brazil (62 903 tonnes), Uruguay (52 081 tonnes) and Canada (25 709 tonnes) (see footnote 3). The largest importers of rendered animal protein meals in 2008 were Indonesia (309 679 tonnes), followed by Thailand (149 490 tonnes), Viet Nam (114 379 tonnes), Mexico (107 187 tonnes), the United States of America (89 675 tonnes), China (62 905 tonnes), Egypt (62 276 tonnes), Chile (53 141 tonnes), Bangladesh (50 315 tonnes), Philippines (50 054 tonnes), Taiwan Province of China (42 190 tonnes), Russia (38 610 tonnes) and South Africa (35 919 tonnes) (see footnote 3).

Data for global rendered fats and greases are only currently available for tallows, with total global tallow exports and imports reported at 1 878 661 tonnes in 2008. The major tallow exporters were the United States of America (1 040 926 tonnes), Australia (372 532 tonnes), Canada (183 765 tonnes) and New Zealand (148 405 tonnes), and the major tallow importers in 2008 were Mexico (516 266 tonnes), China (365 351 tonnes) and Nigeria (123 567 tonnes) (see footnote 3).

Miscellaneous invertebrate terrestrial products

No statistical information is available concerning the total global production of terrestrial invertebrate animal products, the majority being highly localized and serving as supplementary feed items or for use within farm-made aquafeeds (Hasan *et al.*, 2007).

Plant nutrient sources

The major plant dietary nutrient sources, including meals and oils, available in the market place can be listed as follows (in order of global production and current market availability):

- *Cereals, including by-product meals and oils*: includes milled/processed cereals (maize/corn, wheat, rice, barley, sorghum, oats, rye, millet, triticale, etc.), by-product meals (corn/maize gluten, wheat gluten, dried distillers grains with solubles, rice protein concentrate, rice bran, wheat bran) and extracted oils (corn/maize, rice).
- *Oilseed meals and oils*: includes full-fat (soybean) and solvent-extracted oilseed meals (soybean, rapeseed, cotton, groundnut/peanut, sunflower,

palm kernel, copra), by-product meals (soybean protein concentrates, rapeseed/canola protein concentrate) and extracted oils (palm, soybean, rapeseed, sunflower, linseed, cotton seed, olive).

- *Pulses and protein concentrate meals*: includes milled/processed pulses (peas, lupins) and by-product meals (pea protein concentrate, lupin protein concentrate).

Cereals and by-products

Total global cereal production was 2 525 million tonnes in 2008, up by 33.1 percent from 1 898 million tonnes in 1995, with production growing at an average annual rate of 2.2 percent. Maize production was at 822.7 million tonnes (32.6 percent of the total cereal crop in 2008), followed by wheat at 689.9 million tonnes (27.3 percent), rice paddy at 685.0 million tonnes (27.1 percent), barley at 157.6 million tonnes (6.2 percent) and sorghum at 65.5 million tonnes (2.6 percent). Maize remains the fastest-growing cereal crop, with global production up by 59 percent since 1995 and growing at an annual rate of 3.6 percent (FAO, 2009c).

The largest producer of maize in 2008 was the United States of America at 307.4 million tonnes or 37.5 percent of global production, followed by China (166.0 million tonnes or 20.2 percent), the EU (63.2 million tonnes or 7.7 percent) and Brazil (59.0 million tonnes or 7.2 percent) (FAO, 2009c).

Notwithstanding the above, Asia remains the largest global producer of cereals at 1 188 million tonnes or 47 percent of global production in 2008 (with rice paddy being the main cereal crop at 52.4 percent), followed by the Americas at 646.7 million tonnes or 25.6 percent (with maize being the main cereal crop at 67.8 percent), Europe at 504.4 million tonnes or 20.0 percent (with wheat being the main cereal crop at 49.2 percent), Africa at 151.4 million tonnes or 6.0 percent (with maize being the main cereal crop at 35.1 percent) and Oceania at 34.6 million tonnes or 1.4 percent (with wheat being the main cereal crop at 62.9 percent) (FAO, 2009c).

By country, China maintains the position as the world's top cereal producer at 481 million tonnes (19.0 percent total global production in 2008), followed by the United States of America (403.8 million tonnes or 16.0 percent), the EU (316.2 million tonnes or 12.5 percent), India (266.6 million tonnes or 10.6 percent), Russian Federation (106.4 million tonnes) and Brazil (79.7 million tonnes), these countries accounting for over 65.5 percent of total global cereal production in 2008 (FAO, 2009c).

In marked contrast to cereal production, non-Asian countries currently dominate the cereal export market. For example, the top cereal exporters in 2008 included the United States of America at 80.2 million tonnes, followed by the EU (29.2 million tonnes), Ukraine (24.4 million tonnes), Russian Federation (23.5 million

tonnes), Argentina (22.5 million tonnes), Canada (19.2 million tonnes) and Australia (18.2 million tonnes). The largest cereal exporter in Asia was Thailand (9.3 million tonnes), followed by India (4.0 million tonnes) (FAO, 2009b). Japan continues to be the world's largest cereal importer at over 24.5 million tonnes in 2008, followed by Egypt (15.1 million tonnes), Iran (14.8 million tonnes), the EU (12.5 million tonnes), Mexico (10.2 million tonnes), Saudi Arabia (8.3 million tonnes), Korea Rep. (7.5 million tonnes), Algeria (6.8 million tonnes), Brazil (6.7 million tonnes), Nigeria (5.4 million tonnes), Indonesia (5.3 million tonnes) and Iraq (4.7 million tonnes) (FAO, 2009b).

It is important to mention here that in addition to the above global market overview, the FAO FAOSTAT Agriculture database (www.fao.org/corp/statistics/en) on trade also reports the country exports and imports of specific traded cereal by-product meals and oils, including:

- brans of cereals (buckwheat, barley, fonio, maize, millet, oats, rice, rye, sorghum, wheat);
- cakes of cereals (maize, rice bran);
- flours of cereals (buckwheat, maize, millet, rye, sorghum, wheat);
- germ of cereals (maize, wheat);
- gluten feed and meal (no cereal specified); and
- oils of cereals (maize, rice bran).

Apart from the current absence of statistical information on the total global production of the above-listed cereal by-product meals and oils, the listing currently excludes major wheat by-products (wheat middlings/wheat pollard) and by-products from corn ethanol production. For example, according to the Renewable Fuels Association, ethanol bio-refineries within the United States of America reportedly produced nearly 27 million tonnes of corn cereal by-products for use as animal feed in 2008, including 23 million tonnes of distillers grains (production up ten-fold from 2.3 million tonnes in 1999), 3 million tonnes of corn gluten feed and 600 000 tonnes of corn gluten meal. The estimated market value of feed co-products from ethanol production in 2007/08 was USD3 billion, with an estimated additional USD1.7 billion from the sales of corn oil produced from wet-mill ethanol refineries (Renewable Fuels Association, 2008; Deutscher, 2009).

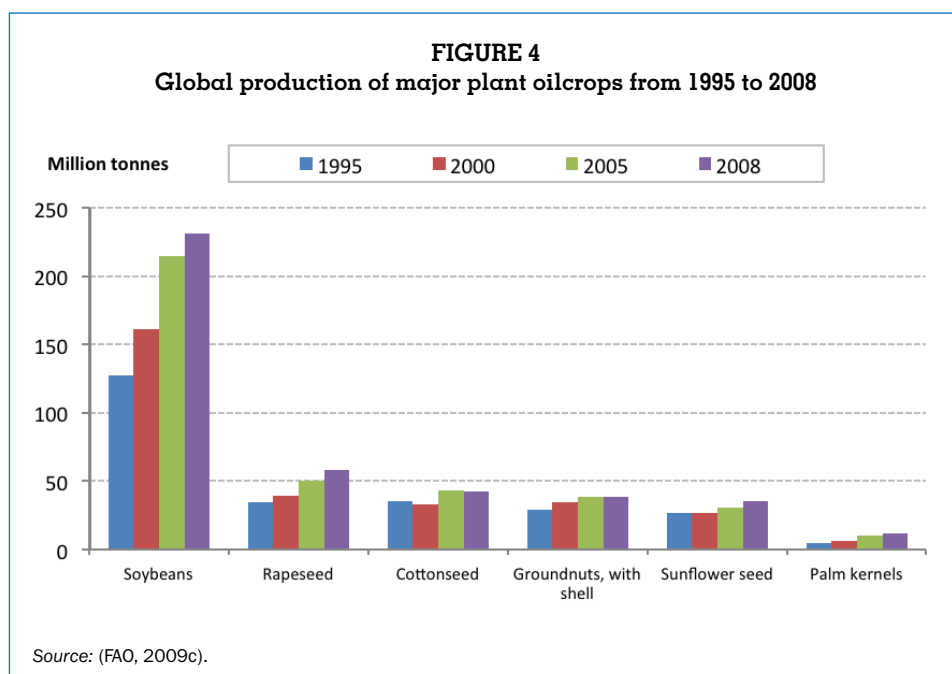
In 2009, distillers grains production was expected to reach 31.5 million tonnes, with exports expected to reach 6.6 million tonnes over the next ten years (Deutscher, 2009). According to the U.S. Grains Council, the United States of America exported over 4.5 million tonnes of dried distillers grains with solubles (DDGS) in 2008, the largest export markets in 2008 being Mexico (1.2 million tonnes or 26.3 percent total exports), followed by Canada (772 000 tonnes or 17.1 percent), Japan (198 000 tonnes or 4.4 percent), Taiwan Province of China (189 000 tonnes or 4.2 percent) and Korea Rep. (185 000 tonnes or 4.1 percent (Chen, 2009).

Oilseed crops, byproduct meals and oils

According to FAO (2009c), the total global production of oilseeds in 2008 was 427 million tonnes, with production up by 61.1 percent since 1995 and growing at an average annual rate of 3.7 percent (Figure 4). Soybean represented 54.1 percent of the total oilseed crop in 2008, followed by rapeseed (13.5 percent), cottonseed (9.9 percent), groundnut (8.9 percent), sunflower seed (8.4 percent) and palm kernel (2.8 percent).

Soybean continues to be the largest and one of the fastest growing oilseed crops, with global production up by 81.9 percent to 230.9 million tonnes since 1995 and growing at an annual rate of 4.7 percent. The largest producer of soybeans in 2008 was the United States of America at 80.5 million tonnes (54.1 percent of total oilseed production), followed by Brazil (59.9 million tonnes or 25.9 percent), Argentina (46.2 million tonnes or 20.0 percent), China (15.5 million tonnes or 6.7 percent) and India (9.0 million tonnes or 3.9 percent (FAO, 2009c). Other major oilseeds produced in 2008 included rapeseed (57.8 million tonnes), cottonseed (42.3 million tonnes), groundnuts (38.3 million tonnes), sunflower seed (35.6 million tonnes) and palm kernel (11.8 million tonnes) (FAO, 2009c).

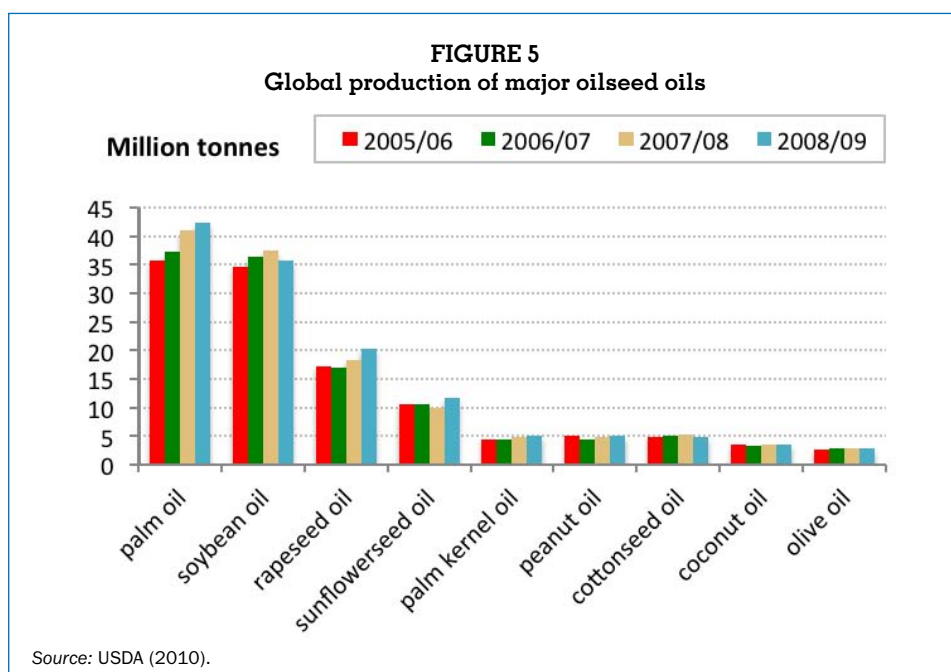
In terms of the total global supply of oilseed protein meals, these follow global oilcrop production, with the largest supply by far being for soybean meal at 151.55 million tonnes in 2008/2009. The largest country producers of soybean meal in 2008/09 were the United States of America (35.47 million tonnes or 23.4 percent), China (32.47 million tonnes or 21.4 percent), Argentina (24.95 million tonnes or 16.5 percent), Brazil (24.33 million tonnes or 16.0 percent),



EU-27 (10.11 million tonnes or 6.7 percent), India (5.98 million tonnes or 3.9 percent) and Mexico (2.73 million tonnes or 1.8 percent) (USDA, 2010).

Other major oilseed protein meals produced in 2008/2009, ranked in order of production volume, included: rapeseed meal (30.76 million tonnes), cottonseed meal (14.44 million tonnes), sunflower seed meal (12.59 million tonnes), palm kernel meal (6.2 million tonnes), groundnut/peanut meal (6.02 million tonnes) and copra/coconut meal (1.90 million tonnes). No published information is currently available for the global production of oilseed protein concentrate meals, including soybean protein concentrate, rapeseed/canola protein concentrate, cottonseed protein concentrate and sunflower seed protein concentrate meals.

In terms of oil supply, palm oil was the top extracted oil produced in 2008/2009 at 42.40 million tonnes (Figure 5), the largest country producers being Indonesia (19.5 million tonnes or 46.0 percent) and Malaysia (17.26 million tonnes or 40.7 percent) (USDA, 2010). The second-largest extracted oil was soybean oil at 35.76 million tonnes, the major producers being the United States of America (8.50 million tonnes), China (7.31 million tonnes), Argentina (6.12 million tonnes), Brazil (6.02 million tonnes), EU-27 (2.31 million tonnes), India (1.34 million tonnes) and Mexico (0.61 million tonnes). Other major oilseed oils produced in 2008/2009, ranked in order of production volume, included: rapeseed oil (20.39 million tonnes), sunflower oil (11.74 million tonnes), palm kernel oil (5.13 million tonnes), peanut/groundnut oil (4.97 million tonnes), cottonseed oil (4.84 million tonnes), copra oil (3.63 million tonnes) and olive oil (2.97 million tonnes) (Figure 5).

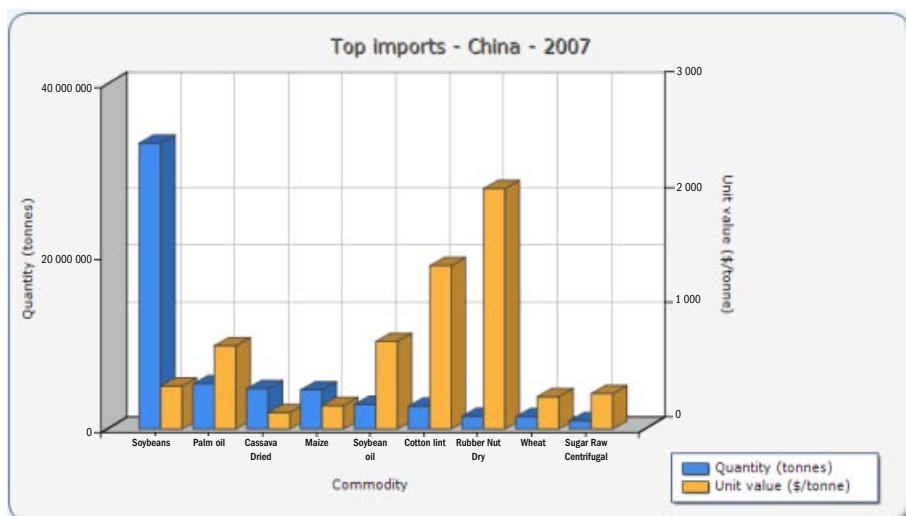


As with the cereals corn/maize and wheat, over 85 percent of global oilcrop exports currently originate from within the Americas (FAO, 2009b), including the United States of America (45.5 percent and 14.8 percent global soybean and soybean meal exports, respectively), Brazil (39.1 percent, 25.0 percent and 21.0 percent of global soybean, soybean meal and soybean oil exports, respectively), Canada (63.7 percent, 54.8 percent and 64.5 percent of global rapeseed, rapeseed meal and rapeseed oil exports, respectively) and Argentina (7.3 percent, 46.0 percent and 52.0 percent total soybean, soybean meal and soybean oil exports, respectively) (USDA, 2010).

China continues to be the world's largest importer of oil crops (46.6 million tonnes or 48.0 percent of global oilcrop imports in 2008/2009 (FAO, 2009b), including 53.7 percent of global soybean imports, 28.1 percent global soybean oil imports, 24.7 percent of global rapeseed imports, 18.4 percent of global rapeseed oil imports, and 18.0 percent of global palm oil imports (Figure 6).

The second largest importer of oilcrops was the EU, which imported 18.6 million tonnes or 19.1 percent of global oil crop imports in 2008/2009, including 57.2 percent of global sunflower seed meal imports, 41.9 percent of global soybean meal imports, 31.7 percent of global sunflower seed imports, 27.2 percent of global rapeseed imports, 26.0 percent of global sunflower seed oil imports and 18.4 percent of global rapeseed oil imports (FAO, 2009b).

FIGURE 6
Top agricultural imports by quantity in China in 2007



Source: FAO (2009b).

Pulses and protein concentrate meals

For the purposes of this paper, only peas and lupins will be considered, as their protein concentrate meals are commercially available for use within compounded animal feeds, including aquaculture feeds.

The total global production of dry peas was 9.8 million tonnes in 2008, with production down by 14.2 percent from 1995. The major country producers in 2008 included Canada (3.57 million tonnes or 36.3 percent of global production), followed by the Russian Federation (1.25 million tonnes or 12.8 percent of global production), China (900 000 tonnes), India (800 000 tonnes), the United States of America (556 560 tonnes), Ukraine (454 900 tonnes), France (446 850 tonnes), Australia (252 000 tonnes) and Ethiopia (231 934 tonnes) (FAO, 2009c).

The total global production of lupins was 789 617 tonnes in 2008, with production down by 54 percent from 1995. The major country producers in 2008 included Australia (484 000 tonnes or 61.3 percent of global production), followed by Belarus (81 314 tonnes), Germany (50 000 tonnes), Poland (39 686 tonnes), Chile (31 623 tonnes) and the Russian Federation (21 840 tonnes) (FAO, 2009c). At present no information is available concerning the global production of pea and/or lupin protein concentrates.

Microbial ingredient sources

Microbial-derived feed ingredient sources include the use of mass-produced harvested/extracted algae, thraustochytrids, yeasts, fungi, bacteria and/or mixed bacterial/microbial single cell protein (SCP) sources. At present, apart from the limited market availability of algal and thraustochytrid products, the only microbial ingredient sources available in commercial quantities globally are yeast-derived products, including brewer's yeast and extracted fermented yeast products (Tacon, Metian and Hasan, 2010). However, at present no information is available concerning the total global production and market availability of these products.

Current levels of feed ingredient usage and constraints

Based on the results of the global survey concerning feed ingredient usage within compound aquafeeds for the major cultivated finfish and crustacean species, the following trends are evident and are discussed individually in the sections which follow:

- Continued use of fishmeal and fish oil as major dietary animal protein and lipid sources.
- Increased use of terrestrial animal protein meals and oils as dietary nutrient sources.
- Continued and increased use of plant protein meals and oils as dietary nutrient sources.

- Ingredient competition with other users.
- Continued growing importance of feed and food safety.

Continued use of fishmeal and fish oil as major dietary animal protein and lipid sources

Fishmeal and fish oil continue to be the major sources of dietary protein and lipid within compound aquafeeds for the higher-trophic-level fish and crustacean species, e.g. eel (fishmeal: 55–65 percent, fish oil: 3–18 percent, total: 58–83 percent), marine finfish (fishmeal: 20–65 percent, fish oil: 5–20 percent, total: 25–85 percent), salmon (fishmeal: 25–40 percent, fish oil: 10–25 percent, total: 35–65 percent), trout (fishmeal: 18–40, fish oil: 5–25 percent, total: 23–65 percent), shrimp (fishmeal: 5–40 percent, fish oil: 1–9 percent, total: 6–49 percent) and freshwater prawn (fishmeal: 20–65 percent, fish oil: 0–7 percent, total: 20–72 percent).

However, in total usage terms, the largest consumers of fishmeal in 2007 (average species levels based in-part on the results of the global survey) were shrimp (964 000 tonnes or 25.1 percent of total fishmeal used in compound aquafeeds), followed by marine fish (811 000 tonnes or 21.1 percent), salmon (568 000 tonnes or 14.8 percent), freshwater crustaceans (264 000 tonnes or 6.9 percent), trout (253 000 tonnes or 6.6 percent), fed carps (247 000 tonnes), eel (208 000 tonnes 5.4 percent), catfish (196 000 tonnes or 5.1 percent), tilapia (175 000 tonnes or 4.5 percent) and miscellaneous freshwater fish (130 000 tonnes or 3.4 percent). On a global basis, it is estimated that the aquaculture sector consumed 3 843 000 tonnes of fishmeal in 2007 or about 68.4 percent of total reported global fishmeal production for that year.

Similarly, in total usage terms, the largest consumers of fish oil in 2007 were salmon (325 000 tonnes or 39.5 percent total fish oil used in compound aquafeeds), followed by marine fish (203 000 tonnes or 24.7 percent), trout (135 000 tonnes or 16.4 percent), shrimp (96 000 tonnes or 11.7 percent), eels (21 000 tonnes or 2.5 percent), freshwater crustaceans (20 000 tonnes or 2.4 percent) and miscellaneous freshwater fish (18 000 tonnes or 2.2 percent). On a global basis, it is estimated that the aquaculture sector consumed 823 000 tonnes of fish oil in 2007 or about 81.3 percent of total reported global fish oil production for that year.

Despite the continued high dependence of fed aquaculture species production upon the use of fishmeal and fish oil (the aquaculture sector consumed over 4 666 000 tonnes of fishmeal and fish oil or about 70.3 percent of the total global production of these finite ingredients in 2007), there was a wide variation in fishmeal and fish oil usage between major producing countries for individual species. This variation mainly reflects differences between countries concerning the selection and use of fishmeal and fish oil replacers, including the increased use of land animal proteins and fats within feeds for high-trophic-level fish

species and crustaceans within the Americas and Australia due to the absence of government and/or consumer restrictions concerning their use, and the differences in ingredient cost and availability between countries.

It is expected that the total use of fishmeal by the aquaculture sector will decrease in the long term, i.e. from a high of 4 225 000 tonnes in 2005 to 3 843 000 tonnes in 2007 (or 14.2 percent of total aquafeeds by weight) and decrease further to 3 689 000 tonnes by 2020 (or 5.2 percent of total aquafeeds for that year). This decrease is primarily due to the reducing volumes of fishmeal as more of the raw materials are likely to be used for direct human consumption, and the increased use of more cost-effective dietary fishmeal replacers (Davis and Sookying, 2009; Hardy, 2009; Nates *et al.*, 2009; Quintero *et al.*, 2010).

There will continue to be a strong demand for fish oil in aquaculture diets, but as already discussed, production volumes are likely to remain static or indeed fall with a reduction in raw material. Also, there is a growing demand for fish oil for direct use in human supplements and pharmaceutical medicines. This market is likely to be able to pay a premium for oil, resulting in aquaculture having to reduce its usage. This, combined with the growth in aquaculture, would mean a considerable reduction in the dietary inclusion levels. This would not have any deleterious effect on the health of the farmed organisms but would reduce the health-giving benefits of the final products imparted by the long-chain highly unsaturated fatty acids, including eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3) (Turchini *et al.*, 2009; Wang, 2009).

Alternative lipid sources to fish oil are being used in greater amounts (Turchini, Torstensen and Ng, 2009). Key alternatives include vegetable oils (preferably those with high omega-3 content) and poultry oil. Oils from farmed fish offal are also potential omega-3 sources for other farmed fish. The production of marine microalgae or bacteria with very high content of highly unsaturated fatty acids (HUFA) is currently expensive for use in most aquaculture feeds, but as production methods become more cost-efficient, the situation is likely to change.

Increased use of terrestrial animal protein meals and oils as dietary nutrient sources

The use (within non-European countries) of terrestrial animal protein meals (poultry by-product meal – PBM, hydrolyzed feather meal – HFM, blood meal – BM, meat meal – MM, meat and bone meal – MBM) and lipids (poultry oil – PO) is increasing within compound aquafeeds for both high and low-trophic-level species, e.g.:

- Salmon (PBM 10–30 percent, HFM 5–12 percent, BM 1–8 percent, MM 10–30 percent, PO 1–15)
- Trout (PBM 5–30 percent, HFM 5–20 percent, BM 1–8 percent, MM 10–30 percent, PO 1–15 percent)
- Marine finfish (PBM 10–30 percent, BM 1–10 percent, MM 10–30 percent, PO 1–10 percent)

- Shrimp (PBM 2–30 percent, HFM 5–10 percent, MM 2–30 percent)
- Catfish (PBM 2–4 percent)
- Tilapia (MBM 5–10 percent, PO 2–4 percent)
- Freshwater crayfish (MM 10–30 percent, MBM 10–30 percent)
- Carp (MBM 5–10 percent)
- Grey mullet (MBM 5–10 percent).

The fact that non-European feed manufacturers are able to utilize this largely untapped dietary nutrient source allows them to be less reliant on the use of fishmeal and fish oil as dietary nutrient sources, and by virtue of greater availability and lower cost of these terrestrial meals and oils, makes them more economically competitive than their European counterparts. For example, salmon feeds in Chile currently contain about 10–20 percent terrestrial animal by-products and only 20–25 percent fishmeal and 12–15 percent fish oil, whereas in the UK salmon feeds contain 35 percent fishmeal, 25 percent fish oil and 0 percent terrestrial animal by-products. Despite the above, it is estimated that the total direct usage of terrestrial animal by-product meals and oils within compound aquafeeds is currently only between 150 000 tonnes (lower range limit) and 300 000 tonnes (upper range limit) or less than 1 percent of total global compound aquafeed feed production. Clearly, there is considerable room for further growth and expansion (Nates *et al.*, 2009).

According to the European Commission, the only animal by-products (ABP) which can be used within aquafeeds are Category 3 ABP (European Commission Regulation No. 1774/2002 and No. 999/2001), namely those animal by-products or parts of slaughtered animals which are fit for human consumption in accordance with Community legislation but are not intended for human consumption for commercial reasons, including:

- Fishmeal (with restrictions – intra-species recycling is prohibited, see Regulation EC 999/2001)
- Dicalcium phosphate and tricalcium phosphate of animal origin (with restrictions)
- Non-ruminant blood meal and blood products (with restrictions)
- Milk, milk-based products and colostrums (without restriction)
- Eggs and egg products (without restriction)
- Hydrolyzed protein from ruminant hides/skin (without restriction)
- Hydrolyzed protein from non-ruminants (without restriction)
- Gelatine from non-ruminants (without restriction)
- Animal fats (without restriction)
- Collagen from non-ruminants (without restriction).

Continued and increased use of plant protein meals and oils as dietary nutrient sources

Plant proteins (soybean meal – SBM, wheat gluten meal – WGM, corn gluten meal – CGM, rapeseed/canola meal – R/CM, cottonseed meal – CSM, canola

protein concentrate – CPC, sunflower seed meal – SSM, groundnut/peanut meal – G/PM, mustard seed cake – MC, lupin kernel meal – LKM, faba bean meal – FBM, field pea meal – FPM) and oils (rapeseed/canola oil – R/CO, soybean oil – SO) represent the major dietary protein and lipid sources, respectively, used within feeds for lower-trophic-level fish species (e.g. tilapia, carp, catfish) and the second major sources of dietary protein and lipid after fishmeal and fish oil within shrimp feeds and European high-trophic-level fish species, e.g.:

- Tilapia (SBM 20–60 percent, CGM 5–10 percent, R/CM 20–40 percent, CSM 1–25 percent, SO 1–8 percent)
- Carp (SBM 5–25 percent, R/CM 20–40 percent, G/PM 30 percent, MC 10 percent)
- Shrimp (SBM 5–40 percent, WGM 2–10 percent, CGM 2–4 percent, R/CM 3–20 percent, LKM 5–15 percent)
- Marine fishes (SBM 10–25 percent, SO 3–6 percent, WGM 2–13 percent, CGM 4–18 percent, SSM 5–8 percent, R/CM 7–20 percent, CPC 10–15 percent)
- Trout (SBM 3–35 percent, WGM 2–10 percent, SSM 5–9 percent, CGM 3–40 percent, R/CM 2–10 percent, LKM 5–15 percent, FBM 8 percent, FPM 3–10 percent, R/CO 5–15 percent, SO 5–10 percent)
- Salmon (SBM 3–12 percent, WGM 2–10 percent, SSM 5–9 percent, CGM 10–40 percent, R/CM 3–10 percent, LKM 5–15 percent, FBM 5 percent, FPM 3 percent, R/CO 5–15 percent, SO 5–10 percent)
- Milkfish (SBM 35–40 percent)
- Grey mullet (SBM 20–25 percent)
- Freshwater prawns (SBM 15–25 percent)
- Colossoma (SBM 13 percent, CGM 6 percent)
- Freshwater crayfish (WGM 2–10 percent, LKM 5–30 percent)
- Eel (SBM 8–10 percent).

Soybean meal is currently the most common source of plant protein used in compound aquafeeds and the most prominent protein ingredient substitute for fishmeal in aquaculture feeds⁴, with feeds for herbivorous and omnivorous fish species and crustaceans usually containing (depending upon species, country, price and availability) from 15 to 45 percent soybean meal, with a mean of 25 percent in 2008. In global usage terms and based on a total compound aquafeed production of 27.1 million tonnes in 2007, it is estimated that the aquaculture feed sector is currently consuming about 6.8 million tonnes of soybean meal; China alone, currently consuming an estimated 6.0 million tonnes of soybean meal within compound aquafeeds (Mike Cremer, personal communication, American Soybean Association 2009).

⁴ Source: Paper presented by L. Manomaitis. *Improving Southeast Asian aquaculture through feeds and technology*. 17th Annual ASAIM SEA Feed Technology and Nutrition Workshop, Imperial Hotel, Hue, Vietnam, June 15–19, 2009 (see www.asaimsea.com/download_doc.php?file=FTNW09-Lukas.pdf).

At present, plant protein/oil choice and selection is based upon a combination of local market availability and cost, and the nutritional profile (including antinutrient content and level) of the protein meal and/or plant oil in question (Davis and Sookying, 2009; Gatlin *et al.*, 2007; Lim, Webster and Lee, 2008; Krogdahl *et al.*, 2010). However, there is no doubt that with the continued rise in the price of fishmeal, plant protein concentrates will be increasingly preferred over regular plant protein meals in aquafeeds for high-trophic-level cultured species and crustaceans (includes soybean protein concentrate, canola protein concentrate, pea protein concentrate, corn/wheat gluten meals, etc.; for review see Tacon, Metian and Hasan, 2010). For example, according to L. Manomaitis (see footnote 5) the forecast demand for soybean protein concentrates within aquafeeds is expected to be over 2.8 million tonnes by 2020.

Ingredient competition with other users

Aquaculture, like any other animal production system, has to compete with other users for nutrient inputs, including specific feed ingredients and fresh food items.

Competition with livestock

Livestock are an integral part of the agricultural food production process within all of the countries where aquaculture is practiced and are an important food provider in the form of nutrient-rich meat, eggs, milk and other dairy produce. It follows therefore that livestock are also a major consumer of feed ingredients and feeds. Total global livestock and animal feed production is estimated at 708 million tonnes in 2009 (poultry – 41.5 percent, pig –30.0 percent, ruminant – 25 percent), with total global feed production up by 20 percent since 1995 and growing at an average annual compound rate of 1.3 percent since 1995 (Best, 2010b).

Although aquaculture's contribution to global animal feed production is currently less than 4 percent by volume, it has emerged as a major competitor and consumer for several key ingredient sources, including fishmeal and fish oil. As mentioned previously, it is estimated that the aquaculture sector consumed over 4.7 million tonnes of fishmeal and fish oil or about 70.3 percent of the total global production of these commodities in 2007. Despite this, in China (the world's largest global producer of pigs and aquaculture products), the largest consumer of fishmeal remains the livestock and poultry sector (52 percent of total Chinese fishmeal demand in 2008), the estimated demand for fishmeal within pig starter/piglet diets alone being 612 000 tonnes (Wang, 2009). For example, according to Wang, (2009), animal feed production in China during the first half of 2009 was reported as follows: total national feed production – 64.63 million tonnes (down by 5.4 percent from the previous year), pig feed – 23.3 million tonnes (up 1.8 percent), poultry feed (meat) – 18.5 million tonnes (down 12 percent), poultry feed (egg) – 11.12 million tonnes (down 15.8 percent), aquatic feed – 7.85 million tonnes (up 17.3 percent), ruminant feed –

2.15 million tonnes (down 24.6 percent) and others – 1.6 million tonnes (up 5.7 percent). According to J. Shepherd⁵, the major consumers of fishmeal in China in 2008 were aquaculture – 58.8 percent, pig – 30.9 percent and poultry – 9.1 percent. For fish oil, the 2010 estimates for major consumers were aquaculture – 80 percent, refined edible – 12 percent and industrial – 7 percent. In contrast, aquaculture currently uses 760 000 tonnes of fishmeal, accounting for 76 percent of Europe’s fishmeal consumption⁶.

Competition with pet food

The pet food industry represents a relatively new and rapidly growing non-food animal sector, with dog and cat feed sales totalling USD9 billion in 2008 (Gianni Carniglia, GyB Ltd., Chile, personal communication, 2009). The dog and cat feed sector is currently one of the largest consumers of terrestrial animal protein meals and fats, including poultry by-product meal and meat and bone meal, the petfood industry representing 45 percent of the PAP’s outlets in the EU⁷ and 9 percent of rendered meal usage in Australia⁸. Moreover, compared with the other conventional animal feed sectors (including the aquaculture sector), the high-value and lucrative pet food sector is willing to pay top dollar for “pet food grade” low ash poultry by-product meals, which results in many of these products being out of the economic grasp of other users, including aquatic feed producers (for review, see Aldrich, 2006). A similar situation exists for the competition for fresh fish and aquaculture by-product meals for use within tinned cat foods and dog foods (De Silva and Turchini, 2008).

Competition with biofuels

Increasing petroleum costs, concern for the climate and the need to reduce greenhouse gas emissions have focussed efforts on the identification of alternative, renewable sources of energy, including conventional food grains and oilseeds, plant/animal oils and by-products, and low-value cellulosic wastes as substrates for the production of biofuels, including ethanol and biodiesel. Notwithstanding the ecological, environmental, economical and ethical problems involved in the use of some of these products for biofuel production, it is sufficient to note that many countries/governments have now adopted biofuel production as a national priority, with the sector in some countries enjoying a variety of government subsidies and incentives (for review, see FAO, 2008a).

Most concerning is the diversion of potential existing food grains and crops (including the land and resources used to produce them) from direct human

⁵ Source: Presentation by J. Shepherd on *Past and present priorities*. Annual Conference of the International Fishmeal and Fish Organization, 5–8 October 2009, Vienna, Austria.

⁶ Source: Presentation by M. Thomsen on *Fishmeal Europe 2009*. Annual Conference of the International Fishmeal and Fish Organization, 5–8 October 2009, Vienna, Austria.

⁷ Source: Presentation by N.C.L. Nielsen on *Updates Europe*. 76th Annual Convention of the National Renderers Association, San Francisco, USA, October 23, 2009.

⁸ Source: Presentation by C. Palmer on *Australian rendering industry update*. 76th Annual Convention of the National Renderers Association, San Francisco, USA, October 23, 2009.

consumption to more profitable biofuel production for use as a “greener” petroleum substitute. Often this market advantage is artificial because of government subsidies and incentives, but regardless, it leads to less grains and crops being available for direct human consumption and increased demand for these commodities and consequent increased food prices (for review, see Swisher, 2009). On the positive side, as mentioned previously, a variety of new feed by-product meals will be produced and be available from ethanol biorefineries, including distillers grains, corn gluten feed and corn gluten meal.

Competition with humans

Last but not least, there is the direct competition between the use of fish for aquafeeds and the use of the same resources as a direct food for humans. This includes competition for fresh or frozen fish used as a direct feed source (estimated usage by Chinese aquaculture being between 6 and 8 million tonnes in 2008), or for fish used in production of fishmeal and fish oil (for review, see FAO, 2008b; Funge-Smith, Lindebo and Staples, 2005; Hasan and Halwart, 2009; Tacon and Metian, 2008a, 2009a,b).

Continued growing importance of feed and food safety

Food safety risks associated with the use of aquaculture feeds may result from the possible presence of unwanted contaminants, either within the feed ingredients used or from the external contamination of the finished feed during prolonged storage. For example, major animal feed contaminants reported to date have included salmonellae, mycotoxins, veterinary drug residues, persistent organic pollutants, agricultural and other chemicals (solvent residues, melamine), heavy metals (i.e. mercury, lead, cadmium) and excess mineral salts (i.e. arsenic, hexavalent chromium, selenium, flourine) and possible transmissible spongiform encephalopathies (TSE). Apart from the direct negative effect of these possible contaminants on the health of the cultured target species, there is also a risk that some of these feed contaminants may be passed along the food chain, via contaminated aquaculture produce, to consumers.

In recent years, public concern regarding food safety has increased as a consequence of the increasing prevalence of antibiotic residues, persistent organic pollutants and chemicals in farmed seafood (for review, see Berntssen and Lundebye, 2008; Karunasagar, 2009; Lie, 2008; Lightner *et al.*, 2009; Tacon and Metian, 2008b).

Conclusions and recommendations

Reduce country dependence upon imported feed ingredient sources

On the basis of the results obtained from the feed ingredient survey conducted for this paper, it is apparent that many aquaculture-producing countries are currently highly dependent upon imports for sourcing the feed ingredients used

in their aquaculture feeds. Although the results of this survey should be treated with caution (as the results indicate the best estimates of individual country respondents rather than official government statistics), they do indicate some significant findings, as follows:

- Countries that reportedly import less than 25 percent of their feed ingredients used in compound aquafeeds include: Argentina (0–10 percent), Brazil (0–10 percent) and the United States of America (5–10 percent).
- Countries that reportedly import 25 to 50 percent of their feed ingredients used in compound aquafeeds include: Australia (25–35 percent), Canada (40 percent), Denmark (30 percent), India (0–44 percent) and Mexico (20–45 percent). In the case of India, feed ingredient imports can vary from 0 percent for freshwater Indian major carp feeds using locally available feed ingredient sources to as high as 44 percent for shrimp feeds.

For example, according to a recent survey concerning the animal feed manufacturing sector in Mexico (CONAFAB, 2008), Mexico was ranked fourth in the world in terms of total animal feed production (26.2 million tonnes in 2008, with aquaculture representing less than 1 percent of total feed production or 230 000 tonnes). The country imported over 55 percent of all the ingredients used within the animal feed sector, including over 90 percent of all plant oilseeds.

- Countries who reportedly import 50 to 75 percent of their feed ingredients used in compound aquafeeds include: Chile (30–80 percent), China (>50 percent), Ecuador (60–70 percent), Egypt (54–75 percent), France (50–78 percent), Italy (70–75 percent), Turkey (70 percent), the United Kingdom (60–90 percent) and Viet Nam (30–70 percent).
- Countries who reportedly import 75 to 100 percent of their feed ingredients used in compound aquafeeds include: Greece (90 percent), Korea Rep. (90–100 percent), Norway (80–90 percent), Peru (70–90 percent), Taiwan Province of China (50–100 percent), Tahiti (100 percent) and the United Kingdom (60–90 percent).
- Although no information was forthcoming from several other major aquaculture producers in Asia (including Bangladesh, Indonesia, Japan, Philippines and Thailand), published information suggests that in the Philippines 40–60 percent and 85–95 percent of the feed ingredients used for fish feeds and shrimp feeds are imported, respectively (Sevilla, 2007). A similar situation is expected to exist in Indonesia, Malaysia and Thailand (see SES, 2009a,b,c).
- The current dependence of aquaculture-producing countries upon the importation of major protein ingredient sources and lipids (i.e. fishmeal, soybean meal, fish oil) is strongest within those countries where production focus is on exports and/or the production of high-trophic-level fish and shrimp (SES, 2009a).

- In general, the demand for imported feed ingredient sources is highest within those developing countries with a strong commercial animal feed manufacturing sector and dominated by larger integrated farms and larger independent farms (SES, 2009c).
- In-country feed ingredient availability and usage within most developing countries is usually biased toward energy-rich rather than protein-rich ingredient sources, with greatest usage of local non-imported ingredients being within compound feeds intended for the production of freshwater and brackishwater fish feeds targeted for domestic consumption (SES, 2009a,b) and within farm-made aquafeeds produced by small-holder farmers (SES, 2009c).
- Many governments will continue to actively promote reduction of the current dependency of their national animal feed manufacturing industries upon imported feed ingredient sources by developing more competitive protein and energy sources from locally available agricultural products, including cassava, rice, oil palm, copra, etc. (SES, 2009a,d).

Select feed ingredients that can be sustainably produced and can grow with the sector

As mentioned at the outset of this paper, if finfish and crustacean fed aquaculture production is to maintain its current average annual growth rate of 8 to 10 percent to 2025, then the external supply of nutrients and therefore feed ingredient sources will also have to grow at similar rates.

Included within these ingredient sources are:

- fishery by-products and aquaculture by-product meals and oils;
- invertebrate fishery by-product meals and oils;
- terrestrial animal by-product meals and fats;
- cereals, including by-product meals and oils;
- oilseed meals and oils;
- pulses and protein concentrate meals; and
- microbial ingredient sources.

It follows from the above that ingredient choice should be based not only on nutrient level, digestibility and cost, but also upon other criteria such as sustainability and environmental impact of production, and fish in: fish out ratio (FIFO) (Naylor *et al.*, 2009; Jackson, 2010; Kaushik and Troell, 2010).

The limited supply of fishmeal and fish oil from wild fisheries and the continued strong demand for these products have led to concerns about the long-term sustainability of the fisheries and their level of responsible management. It is therefore important that care is taken to ensure that any fishmeal and fish oil made from whole wild fish comes from fisheries that have been managed according to the *FAO Code of Conduct for Responsible Fisheries* (FAO, 1995).

Minimize environmental and ecosystem impact of feeds and feeding regimes

As mentioned above, major criteria for ingredient selection are nutrient density and digestibility. It follows, therefore, that the higher the nutrient digestibility of a particular ingredient (or complete feed containing the ingredient), the higher its nutrient utilization efficiency and consequent resultant growth of the target species. Moreover, by using highly digestible feed ingredient sources and feeds, nutrient loss and feed wastage are kept to a minimum, thereby also minimizing any possible negative environmental and ecosystem impacts.

In addition to the direct selection of highly digestible feed ingredient sources, nutrient loss and nutrient impacts from feeds can also be negated by integrating production with other cultured species which can benefit from these nutrient waste streams (Duarte *et al.*, 2009; Soto, 2009) or by culturing the species under closed biofloc-based zero-water exchange culture conditions (Avnimelech, 2009).

Of particular note is the ability of biofloc-based zero-exchange production systems to essentially change the nutrition of the target species (usually either marine shrimp or tilapia) from that of a purely monogastric animal dependent upon the external supply of a nutritionally complete diet, to an animal cultured within a nutrient-rich microbial soup capable of supplying nutrients to the cultured species (both shrimp and tilapia are able to filter out these microbial flocs) in addition to the diet being fed, with consequent feed cost savings and ability to better utilize ingredient sources with inherent nutrient deficiencies or imbalances (Tacon *et al.*, 2002, 2006).

Give special attention to small-scale farmers using farm-made aquafeeds

It is widely recognized that small-scale farmers still form the backbone of Asian aquaculture, in particular, for the production of freshwater fish species for domestic consumption. One of the hallmarks of this sector is the use of farm-made aquafeeds. However, apart from the general absence of statistical information on the size and extent of this sector, little or no attention is given to helping farmers better formulate and manage their feeds. To a large extent, this has been due to the thrust by government agencies and feed manufacturers to move the sector away from the use of farm-made feeds to the purchase of commercially manufactured aquafeeds.

Despite the relative merits and demerits of using farm-made aquafeeds (New, Tacon and Csavas, 1995; Hasan *et al.*, 2007), there is an urgent need to better assist the generally resource-poor farmers using farm-made aquafeeds, not only by improving feed formulation, minimizing the use of unnecessary feed additives and chemicals (including antibiotics), but by improving on-farm feed management and thereby reducing feed wastage and potential deleterious environmental impacts.

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Improving aquaculture governance: what is the status and options?

Expert Panel Review 2.1

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Abstract

This paper examines aquaculture governance from a global perspective, looking at its current status and the role of governments in administering and regulating aquaculture, including licence procedures, possible strategies and policy instruments. It also looks at the role and responsibilities of other stakeholders, such as industry, non-governmental organizations and communities.

Over the past decade, considerable progress has been made in addressing aquaculture governance issues. For example, many governments worldwide utilize the FAO *Code of Conduct for Responsible Fisheries* (CCRF), particularly its Article 9. They also use the FAO published guidelines for reducing administrative burdens and for improving planning and policy development in aquaculture, and several countries have defined adequate national aquaculture development laws, policies, strategies and plans. Moreover, individual countries have used best management practices (BMPs) and manuals on farming techniques which have

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been promoted by industry organizations and development agencies. The aim is to ensure an orderly and sustainable sector development. However, aquaculture governance remains an issue in many countries. Some of its manifestations include conflicts over marine sites, disease outbreaks that could have been prevented, a widespread public mistrust of aquaculture in certain countries, inability of small-scale producers to meet foreign consumers' quality standard requirements and inadequate development of the sector in certain jurisdictions despite favourable demand and supply conditions.

There are other key observations that emerge from this global perspective of aquaculture governance. Firstly, the importance of governance cannot be overstated. It is as critical to successful aquaculture as feed, seed, capital and technology. Without good governance aquaculture operations will not appear or will not last. Markets and inputs may exist, but unless there are individuals willing to spend time and money, and take on risks, aquaculture operations will not endure. Secondly, private-sector entrepreneurs are the drivers behind durable aquaculture. Their operations may be capital intensive or low-input intensive, but their motivation is risk-adjusted net income, as with agriculture. Hence, secure exclusive rights to the property and proceeds, including protection from arbitrary confiscation of farms, are among the minimum conditions for private-sector investment. Such property rights are among the factors that underpin an "enabling environment". Other factors include economic and political stability, the rule of law, low levels of corruption, and effectiveness and efficiency of government services. If they are in place, and markets and inputs exist, entrepreneurs are more likely to invest in aquaculture. Thirdly, the behaviour of entrepreneurs must be circumscribed. This can be done by economic incentives, peer pressure or regulations. The ideal would be for self-regulation, because then entrepreneurs' sense of corporate governance would value all stakeholders, including future generations. Unfortunately, experience has demonstrated that many entrepreneurs will ignore negative externalities in their pursuit of profits. Hence, their behaviour must be modified so their interests are reconciled with those of society. In addition, there are problems in society that are not of farmers' own making and cannot be mitigated even by responsible practices. These problems – usually the result of social dysfunctions – also underline the need for regulation. Finally, because the goal of aquaculture governance is to maintain a sustainable industry, the three observations above must be acknowledged by policy-makers. Not only must an enabling environment permit entrepreneurs to create a profitable and competitive industry, mitigate or avoid negative externalities and be granted the social licence to operate, but also policy-makers must learn from best practices elsewhere and implement them. The industry also has an important responsibility to work with policy and rule-makers so that regulations, especially, are not excessively restrictive and prone to circumvention. Mariculture governance will require particular attention.

KEY WORDS: *Aquaculture, Governance, Development, Global trends, Sustainable aquaculture.*

Introduction

Governance has become a focus of studies because of its importance. A recent study compared agricultural sectors across 127 countries (Lio and Liu, 2008). Using World Bank governance indicators, it demonstrated that the primary explanation for differences in agricultural productivity was the quality of governance. Those countries which ranked higher in the governance indicators tended to have higher agricultural productivity. Political, institutional and legal environments were statistically significant compared with other explanatory variables such as differences in precipitation or the number of tractors. Not all World Bank governance indicators were equally important in explaining agricultural performance. The rule of law, control of corruption, effectiveness of government and regulatory efficiency were the most important. Moreover, divergences in agricultural productivity widened over time because of governance. Countries with good governance initially had greater agricultural output with a given input, but they also had higher investment and capital accumulation. With growing capacity over time, the initial divergence in agricultural productivity between countries continued to widen. The World Bank has confirmed the critical role of governance in agriculture. In its 2008 World Development Report, the World Bank acknowledged that many of its recommendations on agriculture had failed because of weak governance (World Bank, 2008).

Aquaculture is a primary industry with similar property rights to agriculture, and its productivity and long-term growth are equally dependent on governance. As the Bangkok Declaration noted, “effective national institutional arrangements and capacity, policy, planning and regulatory frameworks in aquaculture and other relevant sectors are essential to support aquaculture development” (NACA-FAO, 2000). The focus of government intervention must be to provide an enabling environment for aquaculture to prosper, while also ensuring that society is protected against market failures. Business-friendly enabling policies, such as security of property rights, enforcement of contracts, and macroeconomic and political stability are important to stimulate entrepreneurship. These must be balanced with policies that reduce risk and costs to society.

Policy implications for the aquaculture sector are clear. Inputs such as seed and technical support are necessary for development of aquaculture but are not sufficient. Governance issues including institutions, the rule of law and the process of policy implementation matter as much, if not more than resource endowments or technical inputs in influencing aquaculture output.

The body of this report consists of three main sections. The first section addresses the question: “What is the current state of knowledge in aquaculture governance?” It also seeks to answer the question: “Who is responsible for what?” Governments, with their panoply of legislative and regulatory controls are stakeholders whose responsibilities need to be clarified. The same

applies to other stakeholders, including producers and their associations, non-governmental organizations (NGOs) and local communities. The next section looks at historical developments in governance since the Bangkok Declaration and answers questions such as: “How has governance changed over the last decade?”, “What are the trends?”, and “Has aquaculture governance met the expectations expressed in the Bangkok Declaration?” The third major section looks to the future and asks: “What are the emerging issues in aquaculture governance?”, “What are the expectations regarding governance in the future?”, and finally, “What improvements in governance are recommended?” This review does not offer definitive answers but suggests the consideration of practices that have been successful in different jurisdictions.¹

Current state of knowledge in aquaculture governance

General

Principles of governance

Sustainability is now recognized as the principal goal of aquaculture governance because it enables aquaculture to prosper. Long-term prosperity is predicated on fulfilling the four prerequisites for sustainable aquaculture development: technological soundness, economic viability, environmental integrity and social licence. Meeting these also ensures that human well-being is compatible with ecological well-being. These prerequisites are implicit in the Food and Agriculture Organization of the United Nations’ (FAO) *Code of Conduct for Responsible Fisheries* (CCRF) (FAO,1995a), which provides guidelines that satisfy many of the criteria for good governance in aquaculture. In particular, Article 9.1.1 requires states to “establish, maintain and develop an appropriate legal and administrative framework to facilitate the development of responsible aquaculture” and Article 9.1.3, “the regular up-dating of aquaculture plans to ensure that resources are being used ecologically and efficiently”. There are other articles on the importation of exotic species, the maintenance of genetic diversity and ecosystem integrity and the need for environmental assessment of aquaculture. The CCRF accounts for social factors by requiring access to fishing grounds by local communities (Article 9.1.4) and stakeholder and community participation in developing management practices (Article 9.4.2). In addition, there are articles on postharvest practices and trade.

Broader and softer than “government”, governance covers not only what a government does but also the process by which collective action is taken (Gray, 2005). Thus, aquaculture governance includes how decisions are made and how conflicting interests are reconciled, in addition to the implementation of those decisions. It is therefore broader than the traditional concept of “government”.

¹ Some of the material presented in this report comes from a forthcoming FAO Fisheries and Aquaculture Technical Report on improving aquaculture governance by Nathanael Hishamunda and Neil Ridler.

Type of governance

The type of governance that is closest to “government” is hierarchical, where governments develop policy independently, leaving producers to manage their farms. In some countries, this type of governance has disappeared for practical reasons. This was once the case in Thailand where command and control measures failed to produce sustainable shrimp aquaculture; laws became outdated, enforcement was inadequate and producers non-compliant (Stead, 2005).

A second type is “market governance”. Market governance leaves aquaculture mainly to supply and demand forces. The danger is that market excesses result in unanticipated environmental damage. Such damage occurred with the initial development of commercial milkfish and shrimp farming in Southeast Asia (Hishamunda *et al.*, 2009a). Attracted by aquaculture’s potential to contribute to livelihoods and foreign exchange earnings, governments failed to regulate external costs as farmers pursued myopic profit-maximization. The result was destruction of mangroves and social unrest. Since then, countries in the region and elsewhere have learnt from that experience and have attempted to mitigate negative externalities. In Europe, where market governance predominates (although participatory forms of governance are increasing with coastal aquaculture), market excesses are mitigated by domestic regulations on environmental protection, health and safety (Stead, 2005). Demand-side governance reforms require increased accountability and transparency, and this has resulted in Thailand’s aquaculture governance becoming more participatory and less hierarchical.

The third type of governance is “participatory governance”. This is increasingly the norm in aquaculture, particularly industry self-regulation using codes of practice, and co-management of the sector with industry representatives and government regulators. Participatory governance is exemplified at the local, national and international levels as demonstrated by the following examples:

- At the local level, neighbouring (and competing) farmers work together to co-ordinate environmental and production measures, and compliance is enforced by peer pressure. One example is fallowing and medication of farmed salmon in Scotland (Howarth, 2006). In Norway, the industry is increasingly becoming self-managed, although animal welfare aspects of aquaculture are co-managed (Norwegian Ministry of Fisheries and Coastal Affairs, 2008). Such local self-regulation is behind the “salmon neighbourhoods” which Chile is proposing as part of its strategy to control infectious salmon anaemia (ISA).
- At the national level, several countries have codes of conduct as part of self-regulation. The incentive for farmers to meet these codes is certification of quality, but industry organizations must also have the ability to exclude those which do not comply. There are many national examples of such forms of participatory governance. Canada has a national code of conduct

for responsible aquaculture, Scotland has its “Quality Assurance” scheme and Thailand has its good aquaculture practice (GAP) guidelines for the responsible husbandry of shrimp. Thailand also has a sophisticated code of conduct that demands international quality standards.

- At the international level, an example of self-regulation is the European industry association Federation of European Aquaculture Producers (FEAP). It has a code of conduct that has nine themes that cover, among other issues, environmental protection, consumer concerns, husbandry, socio-economic indicators and the public image of the industry.

Who is responsible for what in aquaculture governance?

The responsibilities of the state

Nature and extent of government intervention in aquaculture

One question that arises in aquaculture governance is the balance between the role of the state and that of the private sector. There is now a consensus that modern aquaculture is driven by the private sector and risk-adjusted profit motives. Such aquaculture need not be large scale but does entail a business orientation as with any small and medium enterprise (SME).

The state must provide an enabling environment, such as secure property rights, political stability, some capital goods (e.g. roads, utilities, etc.), and research and development (R&D), designed to address market failure, in order to reduce costs and risks to entrepreneurs and to protect the interests of the community at large. Without these services, rent seeking rather than efficiency becomes rational behaviour in resource use. The state must intervene to prevent the private sector from concentrating on short-term profits at the expense of the environment and society. Market failures such as externalities, scale economies, asymmetry in information and non-excludability in research require intervention through regulations, economic incentives or a combination of these.

While some public intervention in aquaculture governance is needed, there is less agreement about its extent and timing. Many governments, particularly in developing countries, have successfully provided inputs and services to industry early in the development of aquaculture. For example, in Thailand there was considerable success in producing seed in government hatcheries for distribution to fish farmers early on in the development of its aquaculture industry, and in Viet Nam, in the provision by government of fingerlings of marine species for aquaculture. The government hatcheries also provided training to farmers who eventually set up their own hatcheries. The government hatcheries, unencumbered by mass seed production and commercial chores, then focused on R&D and extension. This also precluded them from competing with the nascent private seed production industry. Governments have also successfully promoted positive externalities, whether through the clustering of small farms or through the nucleus farm programme of Indonesia. However, in other cases, results of government development-oriented policies have been poor or ill-

timed, as was the case of a public seed hatchery in Indonesia, that was made redundant by private hatcheries. Public provision may also be inefficient with perverse incentives. An illustration is public tilapia hatcheries in the Philippines with subsidized seed of questionable quality that undercut private hatcheries (Hishamunda *et al.*, 2009b). In some instances a further argument for reducing the role of the state is the impact on corruption. “The more the state is involved in supplying inputs such as fertilizer and credit..., the greater is the potential for corruption” (World Bank, 2008). Because of these shortcomings, supply-side governance reforms have attempted to curtail the role of the state.

How should the state administer aquaculture?

The regulatory authority

In many countries, particularly where the industry is new or small, the competent authority for aquaculture is the relevant department or ministry in charge of fisheries, and is administered with regulations designed for capture fisheries (Percy and Hishamunda, 2001). Some of the largest aquaculture producers such as China, India and Thailand have lead agencies that fall under their respective ministries of agriculture. In other jurisdictions, the competent authority is neither fisheries nor agriculture. In Chile, for example, responsibility for aquaculture governance falls under the Ministry of Economics, and in Zimbabwe, it is under the Ministry of the Environment and Tourism. In some countries, such as Angola, Mozambique and South Africa, inland aquaculture and marine aquaculture are the responsibility of different ministries.

Where there are different tiers of government, policy-making for aquaculture is best served by a combination of input from high-level and local jurisdictions. In India, there is co-management between central and state governments. A similar arrangement has been made in Canada, another federal country. Canadian federal and provincial ministers have agreed to joint management of aquaculture, with most provincial governments assuming responsibility for site selection through federal-provincial Memoranda of Understanding. In Australia, state (provincial) governments effectively have full legislative control (e.g. of site selection, licensing, management plans, etc.) over aquaculture development and management within their respective geographic boundaries, with the role of the federal government being primarily the management of nationally significant environmental assets and trade-related biosecurity risks.

Whatever ministry or department is responsible, a lead agency for aquaculture is desirable (NACA-FAO, 2000; FAO, 2008a). Its focus would be to co-ordinate, plan and establish regulatory requirements for the industry, integrating aquaculture policy horizontally and vertically. Where such a lead agency does not already exist, a new body can be established. An example is INCOPECA (Instituto Costarricense de Pesca y Acuicultura) in Costa Rica, which was created as the lead agency for the development of aquaculture (and aquaculture research) in 1994. In Honduras, DIGEPESCA (Dirección General de Pesca y Acuicultura) not

only regulates the sector but also prepares aquaculture development plans. The recently established lead agency for aquaculture in Mozambique, INAQUA (Instituto Nacional de Desenvolvimento da Aquicultura), plays the same role. It is responsible for research and the over-sight of incentives, as well as policy development and authorization of licences (INFOSA, 2009).

The advantage of having a lead agency for delivery of aquaculture governance is improved horizontal and vertical integration of administrative and regulatory initiatives, which can be encouraged by decree, for example, the Planning and Building Act in Norway, which obliges agencies to co-operate in terms of delivering multifaceted governance arrangements. In addition to reducing administrative “turf wars”, a lead agency enhances administrative accountability, can be pro-active and can reconcile the many legislative regulations that impinge on aquaculture (FAO, 2008a). The absence of a lead agency can handicap aquaculture: for example, it is argued that marine aquaculture has been stymied in the United States of America by the absence of such an agency at the federal level (Pew Trust, 2007).

Administrative co-ordination is important for licensing procedures, because streamlining licensing procedures facilitates investment. This way, each department does not completely reassess applications or require environmental assessment. One-stop shops where all information is available in one place are advisable. They do not require full institutional integration, merely a common location of applications and information. The lead agency responsible for guiding aquaculture in Norway, the Ministry of Fisheries and Coastal Affairs, provides a one-stop shop for licence applications and for providing time lines for decisions. A refinement to this arrangement is to have front office/back office separations where customers do not meet those who process the applications (FAO, 2007a). This reduces the opportunities for influence peddling.

The legislative and regulatory framework of aquaculture

As a new sector, aquaculture rarely has dedicated laws and rules, and is often regulated under provisions of an existing act (Glenn and White, 2007). Having dedicated legislation in part depends on the relative economic importance of aquaculture compared with other primary industries. In many countries, aquaculture may be merely acknowledged through an enabling clause in fisheries legislation, without specific criteria for licensing. This arrangement may lead to unintended consequences, and leaving discretionary power to officials is susceptible to rent-seeking (Spreij, 2003). On the other hand, if the aquaculture sector is not likely to be an important industry, benefits from a complex legislative framework may not be worth the cost.

Regulations exist to provide an orderly and sustainable development of aquaculture. This is done by reducing negative externalities such as pollution or conflicts over land rights, and by encouraging positive externalities (e.g.

Indonesia's policy of promoting estates in which small-scale aquaculture farms are provided technical assistance by estate management). In the planning and operation stages, a minimum list of regulations would include an environmental assessment, avoidance of unacceptable impacts through the release of exotic species, protection from the ecologically destructive use of resources, control of fish movement to limit transmission of diseases and prevention of intrusions which conflict with the legitimate interests of others (Howarth, 2006).

In addition to regulations that control fish production, fish quality is gaining regulatory attention because quality is important for domestic consumers and for gaining access to international markets. Standards are responding to consumer demands transmitted through retail chains. These retail chains are "buyer-driven" and set quality and sometimes husbandry standards downstream to producers and processors. These standards include quality and hygiene standards and labour regulations, which often requires that fish meet quality standards as specified by hazard analysis and critical control points (HACCP) and by chemical and drug quality control boards with traceability procedures.

In addition to fish quality, animal welfare will require attention from jurisdictions exporting to Europe. This may involve regulations and indicators to ensure that ethical standards are met in the husbandry, transport and slaughtering of fish.

The danger is that compliance with fish quality standards may be prohibitively expensive or technically unfeasible for small-scale farms. In general, regulations can be overly cumbersome, adversely affecting the profitability of aquaculture (Knapp, 2008). By adding further costs such as environmental monitoring, they can make an otherwise viable business economically unprofitable. Excessive regulations also provide opportunities for regulators to enrich themselves (World Bank, 2008). For internationally traded products, over-regulation can destroy comparative advantage if competitors have a framework that is more industry friendly.

This would suggest that regulations should be relevant and be kept to a minimum. Ideally, strong corporate social responsibility of aquaculture farmers would induce "beyond compliance" behaviour (Lynch-Wood and Williamson, 2007). Self-regulation and co-management may be the best policy except for severe and irreversible impacts (Howarth, 2006). In this context, the emerging role of better management practices (BMPs) in aquaculture in developing countries is noteworthy in the absence of an effective state-based system alternative (Tucker and Hargreaves 2008). Cluster-based BMPs are a functional form of participatory governance designed to facilitate smallholder compliance with buyer, consumer and general community expectations about product quality, food safety and environmental integrity (De Silva and Davy 2010). As a form of participatory governance, BMPs more realistically reflect the limitations

of available resources, infrastructure and technology, but also facilitate accountability, innovation and continuous improvement by producers.

In addition to relying on self-management and co-management, there are other options to avoid over-regulation. The lack of enforcement of existing regulations (because of resources) may be more important than weak legislation in explaining unsustainable practices in aquaculture (FAO, 1995b). One means of developing relevant or curtailing unnecessary legislation is to have a mandatory regulatory appraisal process prior to law enactment. This ensures that implementation of the law is considered before and not after its enactment. In addition, periodic reviews of regulations to assess their relevance and effectiveness lessen the likelihood of overlapping laws, regulations and jurisdictions. Overlapping contributes to confusion, inefficiency and bureaucratic rigidity.

As recommended in the Bangkok Declaration, an alternative or complement to environmental regulations as a form of aquaculture governance is the use of economic incentives. Rather than control regulations that explicitly detail pollution levels or methods, economic incentives aim to change behaviour through price or tax signals. They act as a signaling device to farmers to adopt best practices; for example, “payments for environmental services” (PES) are now used in farm carbon emission offsets in Mexico (FAO, 2007b). Their application in aquaculture would encourage the adoption of integrated multi-trophic aquaculture (IMTA) (Soto, 2009).

Some aquaculture strategies and policies

Strategies

An integral part of successful aquaculture governance is a strategy that contains specific instruments to meet development objectives outlined in the overall policy (FAO, 2008a). Among possible supply-side strategies are integrated coastal zone management (ICZM), promotion of foreign investment and encouragement of clusters and large companies.

Integrated Coastal Zone Management

Siting of marine aquaculture development zones is of critical importance to mitigating environmental impacts of aquaculture. Many of the adverse impacts of cage aquaculture can be attributed to siting (Pew Trust, 2007). While siting does not replace good management or regulations, it can make the difference between a sustainable operation and one that fails. At the very least, marine zoning should consider carrying capacity, proximity of sensitive habitats, risks of disease spread and interactions with wildlife (Pew Trust, 2007).

In many countries, siting is the most contentious issue, as it must also take into account potential conflict with other users. Applications for a particular site usually face opposition, whether from cottagers, workers in other sectors, environmental groups or the wider public. In Canada, opposition to sites is

perhaps the major impediment to development of the salmon-farming industry (McConnell, 2006).

A strategy that appears to have been successful in addressing siting-related issues by reconciling different interests is ICZM. ICZM has long been one of the general principles that should guide management of coastal aquaculture development (FAO, 1992). Using the ICZM approach to governance, ecological and human activities that are compatible are incorporated within assigned zones. Such holistic zoning at the beginning of aquaculture development has been an effective tool in preventing conflicts (McConnell, 2006).

ICZM (and associated aquaculture zoning) is the strategy being adopted in many jurisdictions. In Australia, zoning has been proposed in Queensland (Queensland Government, 2008). In Chile, separate sea areas are zoned for salmon farming and the capture fisheries. Similarly, in Belize and the Philippines, zoning is an explicit tool for managing aquaculture. In Namibia, aquaculture zones are a proactive means of promoting the industry in areas which are particularly suitable for aquaculture, and for encouraging the transfer of technology (Republic of Namibia, 2002). In Europe, ICZM is the favoured strategy of the European Commission (EC) to improve both the democratic deficit and the ecosystem deficit (Kaiser and Stead, 2002).

Promotion of foreign investment

One strategy that has been successful in developing aquaculture is to attract foreign investment. It absorbs some of the risks of establishing a new industry and the costs of acquiring technology and knowledge, as well as providing capital.

Costa Rica developed its commercial aquaculture through encouraging foreign investment. One foreign company dominates its tilapia industry. The demand for feed from this company alone was sufficiently large to stimulate feed production by domestic manufacturers. The company also prompted interest in tilapia production by domestic farmers, encouraging emulation and domestic investment in the sector. Similarly, in Africa, Madagascar has adopted policies to attract foreign investment in shrimp farming, and in Mozambique, the two largest shrimp farms belong to foreign (French) investors. In Zimbabwe, the largest farms belong to foreign investors.

In Southeast Asia, foreign ownership is relatively small. In Indonesia, foreign ownership varies by species. Farming of groupers is primarily foreign owned, but ornamental fish operations and seaweed farming are primarily domestic. In Malaysia, the only major foreign participation is in ornamental fish cultivation. Viet Nam has encouraged foreign investors and as a result, the number of foreign companies involved in aquaculture doubled every year between 1998 and 2003. In marine seed production, which Viet Nam has declared a priority, foreign companies are exempt from value added tax (VAT); they also enjoy

reduced land taxes. Feed production is still predominantly by foreign firms, but their share has been declining in favour of domestic producers (Hishamunda *et al.*, 2009a).

However, foreign investment has an economic cost. Investors may also expect tax exemptions and other incentives. Honduras has encouraged its shrimp farming industry by offering tax holidays to foreign investors and the lost tax revenues have reduced multiplier effects for local communities (Stanley, 2003). A further possible cost is non-economic – it is social. Foreign investments can generate resentment among the local population, particularly if the large farm is an enclave-type development, with managers hired from abroad, few backward linkages, little training provided and research done elsewhere. The predominance of foreign-owned companies in British Columbia, Canada, for example, exacerbates NGO opposition to salmon farming.

Clusters and large companies

Small-scale farms often lack technical expertise to meet quality standards and market access. One strategy to mitigate these handicaps is to encourage clustering of farms or the establishment of a large farm. This strategy should encourage many of the benefits from size, including economies of scale in the provision of inputs and of marketing. It could also improve management of watersheds.

One country that has used clusters as a strategy for developing aquaculture is Chile. Aquaculture is ranked high in national policy because it is a sector with high potential with few impediments to growth (Pinto, 2007; Alvarez, 2009). It also benefits from positive locational economies because of geographical concentration in southern Chile, particularly the Xth region. Other examples include the cluster-based approach to development of BMPs and marketing to enhance export markets, for example, the shrimp farming sector in Andhra Pradesh, India (De Silva and Davy, 2010).

A cluster requires a number of attributes: there must be geographical concentration of companies, perhaps caused by agglomeration economies; a strategic inter-relationship with other linked activities; a network of private and public support services and a significant economic and social impact. Aquaculture often meets these criteria. In Chile, to encourage continued expansion of the sector, there is a Strategic Council for the Aquaculture Cluster presided over by the Ministry of Economics.

Another strategy for promoting small-scale farming is a “nucleus” farm. It has been successful in Costa Rica and Jamaica, encouraged in Indonesia and suggested for Mozambique (INFOSA, 2009). In Jamaica, where a large farm already existed (the Jamaican Broilers Group), the farm was able to stimulate backward and forward linkages with its market power and depth of resources.

Its success prompted small-scale farms to “piggy-back” using inputs provided by the large farm. This strategy is followed in Indonesia, where large farms must involve satellite farms. The government’s role has been to facilitate and to monitor these partnerships, suggesting improvements. In Mozambique, where there are no existing nucleus farms, the strategy is to establish them because they are seen as a means of enabling SMEs to acquire technology and economies of scale (INFOSA, 2009).

It seems clustering is a win-win strategy for both the nucleus and satellite farms, implying that there should be no need to use regulations to enforce such strategies, except perhaps at the initial stage, when some level of regulation is necessary so as to achieve more equitable development of the sector, one of the requirements of sustainability.

Policies

Supply-side policy instruments

Most policy instruments to promote aquaculture focus on supply because that is often where there is a constraint. There may be no feed industry or insufficient seed. There may also be diseases and limited funds to curb them, owing to a shortage of investment capital. The usual tool for stimulating supply is a fiscal incentive such as a tax holiday for investors. This may be made available to both domestic and foreign investors. Fiscal policies are less costly to administer than monetary policies; custom exemptions and land tax exemptions can be administered by a few officials. They also do not require an immediate outlay from the public purse, but they bear an opportunity cost of the lost tax revenues for governments.

For the farming of most species, feed is the major operating cost. In most developing countries, access to credit can be equally or more limiting than feed. Many policy options exist to alleviate these constraints, but it is important to note that governance reforms now strive to limit direct provision of inputs by governments because they incite rent seeking by officials (World Bank, 2008). Some needs of industry are beyond the government fiscal capacity of many developing countries, whereas others, such as government assistance with business plans, involve no outlay of public money.

To assist with the shortage and/or the high cost of capital, policy instruments used in aquaculture include cash grants, (e.g. as in Canada), and credit subsidies (e.g. as in Indonesia). Policy instruments that do not involve direct budgetary expenditures have also been implemented. This is the case of government loan guarantees in Europe and state assistance with business plans in Madagascar, which also improved access to bank credit. There may also be the potential for extending the same (crop) insurance available to agriculture, which would reduce the risk premium on bank loans and encourage banks to lend (Van Anrooy *et al.*, 2006). Subsidized interest rates were both inefficient and inequitable

in the Philippines (Hishamunda *et al.*, 2009b). In Côte d'Ivoire, borrowers of government-supervised loans from the African Development Bank viewed loans as handouts with minimal pay-back rates. In the Philippines, subsidized interest rate loans principally benefited the larger borrowers, who had more collateral and less risk. As a result, market, rather than subsidized, interest rates are now charged. There is also the question whether interest rates *per se* are the most important capital constraint for aquaculture farmers, including smallholders, who sometimes are willing to borrow from informal financiers, even at usurious rates. More important than the rate of interest appears to be the ease and convenience of getting a loan approved with minimal paper work and documentary requirements (Hishamunda, *et al.*, 2009b).

In some countries, the quantity and quality of feed constrain the aquaculture sector. Feed cost has tended to increase with the rising price of fishmeal, and feed quality can also be an issue.

Policy instruments to encourage more and better feed production include explicit incentives for foreign investment (e.g. as with Uganda and Viet Nam). Other policies include encouraging livestock companies to diversify into aquaculture and feed production (e.g. as in Jamaica), lowering tariffs on imported feed (e.g. as in the Philippines) and undertaking research to substitute imported fishmeal with local ingredients (e.g. as in Malaysia).

Quality and shortages of seed can also be a constraint. Seed availability can be increased by offering hatcheries tax holidays (e.g. as in Malaysia). Another example is Viet Nam, with its plan to increase marine seed production. Viet Nam also used soft loans, exemptions from VAT and reduced land taxes. To improve the quality of seed, research has been promoted in many countries in public fish stations. Research can also be undertaken by private companies on site, or as in the case of the genetically improved farmed tilapia (GIFT) strain in the Philippines, in collaboration with a university.

Demand-side policy instruments

Governments and producer associations can promote aquaculture through demand-side policy instruments such as marketing incentives. In Jamaica, the government, through the Inland Fisheries Unit, encouraged producers to switch from the Mozambique tilapia (*Oreochromis mossambicus*), which was unpopular with consumers, to the culture of Nile tilapia (*O. niloticus*). It also appointed a marketing officer to create a market for the farmed fish. In Chile, marketing was also a tool for promoting the industry, but through producer associations. Generic marketing of farmed salmon was promoted by collaboration with producer associations of rival salmon-producing countries. In addition, the Chilean Producers' Association engages in brand marketing, as do associations in other countries.

Governments can also ensure fish quality and safety through the hygienic handling and selling of fish. In China, the government played an active role in investing in trading markets. In Thailand, fish can only be sold through fish agents who must be registered with the Department of Fisheries. Similarly, Indonesia assisted with market infrastructure (Hishamunda *et al.*, 2009a).

The responsibilities of other stakeholders in aquaculture governance

Increasingly, corporate self-regulation and decentralization are extending the role of stakeholders, other than governments, in managing aquaculture. Costs of monitoring and enforcement have encouraged delegation of certain husbandry decisions to a collection of neighbouring farms, which are then subject to peer pressure. In addition, communities wish to be part of decision-making in allocating aquaculture sites.

Local communities

Paragraph 6.13 in the FAO's CCRF says that the decision-making process should be timely and transparent, with active participation by stakeholders in fishery decision-making. Involvement by all stakeholders provides legitimacy for aquaculture plans and policies and induces compliant behaviour in enforcing difficult decisions (FAO, 2008a). In various countries, BMPs have been used as a vehicle for engaging local communities in managing environmental impacts of aquaculture to alleviate conflict and to facilitate positive local relations (Tucker and Hargreaves, 2008).

There are several economic arguments for having stakeholders participate in aquaculture decision-making. Firstly, participation should increase acceptance and compliance, thereby reducing transaction and enforcement costs. Secondly, by educating the public, trust in aquaculture should be enhanced, increasing consumer acceptance of farmed seafood. Thirdly, participation encourages the incorporation of local (indigenous) knowledge in decision-making, which could improve productivity. However, while participatory governance of aquaculture has come to the fore in many countries, there are questions about its effectiveness and cost-efficiency. Government officials may use it as a tactic to avoid making decisions. Alternatively, it may be used to “rubber stamp” decisions already made. In addition, obtaining consensus can be expensive, as it requires both human and financial resources.

The question of subsidiarity suggests that certain issues should be left to local authorities. Where there are neither externalities nor economies of scale (as with site selection), local communities are usually able to make their own decisions based on their own priorities. In most of Canadian aquaculture, siting is *de facto*, a provincial responsibility, and in Norway, siting is a responsibility of municipalities. Where there are externalities, as with regulations over importing exotic species, higher-level decision-making is needed. The importation of exotic species is regulated at the regional level within the Southern African

Development Community (SADEC) (SADEC, 2002). The higher-level consideration prevents “environmental dumping”, by which one jurisdiction accepts standards unacceptable to others, a decision that will have negative repercussions on all.

This more local or community driven development (CDD) approach appears to be the route that much aquaculture governance will follow in the future. Linked to decentralization, CDD encourages industry, communities and the local government jurisdiction to decide priorities. There are certain principles that should be followed; in addition to all levels of government (national, provincial, indigenous and urban), there should be representatives of industry and environmental groups (Black *et al.*, 2007). Residents in an area of resource use should be an equal partner in the decision-making process, and more remote urban interests should not dominate the process. All participants in resource allocation decisions must respect all users’ interests and aspirations. CDD is increasingly a focus of development strategies; for example, the World Bank now allocates approximately 10 percent of its funding to CDD strategies (World Bank, 2008).

In spite of its merits, decentralization requires not only local decision-making but also local fiscal capacity. This has also been noted for ICZM implementation. Local tax bases are often low and inflexible. Most developing countries have experimented with decentralization, but have faced resistance to the shift of personnel and the tax base from central to local jurisdictions (World Bank, 2008).

Non-governmental organizations (NGOs)

NGOs can have a constructive role in aquaculture governance and can be a useful counter-weight, particularly where policy-making is *de facto* dominated by business with short-term horizons. NGOs can then act as environmental and social watchdogs and as lobby groups, putting pressure on business to increase transparency and improve working conditions.

They may also be part of aquaculture advisory boards (as in Chile) and publish scientific studies that are not available elsewhere. The latter is particularly important where academic research is limited because of capacity. Their impact on government policy can be important, even if indirect. An example of the constructive role of an NGO is the Dialogue funded by the World Wide Fund for Nature (WWF). Industry representatives, NGOs and other stakeholders meet to develop guidelines to improve sustainability of aquaculture. Traditionally, the Dialogue focused on environmental and ecological challenges facing the farming of different species, but now there are technical committees to examine socio-economic issues.

However, NGOs have certain inherent deficiencies, as they are not accountable, unlike politicians who are often democratically elected. They do not have

to compromise, but merely satisfy single-issue partisans who may not be representative of the broader society. Moreover, reliance on donor funding can lead to sensationalism in order to attract media attention. The result may be vociferous rejection of aquaculture without weighing the benefits that accrue from it. Sometimes they include technical assistance among their functions, without the appropriate or adequate technical expertise.

Producer associations

Producer associations take many forms. They vary from local institutions, sometimes called “one-stop aqua shops”, to sophisticated national organizations. In most countries, aquaculture does not have the economic weight of agriculture or even the capture fisheries. Thus, its interests are often overlooked and therefore producer organizations can be useful just as lobby groups. In addition, they are frequently used as a means of exchanging information and diffusing technical knowledge. The cluster-based approach to farmer associations designed to facilitate aquaculture development has recently seen the emergence of the value chain approach to supply chain reform and broader industry development. This appears to be a viable means by which smallholder farmers can effectively “corporatize” and engage larger-scale producers, processors and buyers in a way that traditional governance mechanisms cannot. In Africa, producer associations have managed shared water supplies and acted as financial intermediaries issuing credit (Hishamunda and Ridler, 2004).

Producer associations can also be marketing agents and monitors for environmental self-policing, as with the Chilean Salmon and Trout Growers’ Association. The association maintains HACCP and quality standards, thereby ensuring that all products exported are of a uniformly high quality. It has also played a major role in marketing farmed salmon, collaborating with other producing countries in generic advertising of salmon, and in differentiating Chilean salmon by brand marketing. Research has also been an important priority for the Chilean association. This association established the Salmon Technology Institute to fund demand-driven research and to encourage the transfer of technology.

Changes in aquaculture governance over the last decade: were the expectations expressed in the Bangkok Declaration met?

More than a decade ago, the FAO identified the principal issues of aquaculture governance as: “how to develop institutions and rules that recognize aquaculture as a distinct agricultural sector; integrate aquaculture concerns into resource use and development planning; improve food safety and quality to safeguard consumers and meet the standards of importers; and improve the management of aquaculture, particularly where it has the potential to be socially or environmentally unsustainable” (FAO, 1995b).

The Bangkok Declaration reiterated the important role that institutions and policies play in the sustainability of aquaculture. It stated that “one of the key issues for the growth of aquaculture will be the ability of countries and organisations to strengthen their institutional capacity to establish and implement policy and regulatory frameworks that are both transparent and enforceable”. The Bangkok Declaration also acknowledged that “the potential of aquaculture to contribute to human development and social empowerment cannot be fully realized without consistent, responsible policies and goals that encourage sustainable development” (NACA-FAO, 2000; Articles 2.15 and 2.17).

Over the past decade, in spite of lacunae, considerable progress has been made in aquaculture governance. The FAO has contributed to this progress through its *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995a) and in particular Article 9. It has published guidelines for reducing administrative corruption and for improving planning and policy development in aquaculture (FAO, 2007a, 2008a). The FAO also provides Internet access to the aquaculture legislation of more than 40 countries, enabling policy-makers to learn from other jurisdictions (FAO, 2010). Improvements in husbandry management have been promoted by industry organizations such as the Federation of European Aquaculture Producers (FEAP) with their “Best Management Practices”, and agencies such as the Network of Aquaculture Centres in Asia-Pacific (NACA), with manuals on farming techniques, development of “aquaclubs” and the introduction of BMPs to smallholder farmers.

Most jurisdictions have improved aquaculture governance. This is in part because governance has become a priority for the World Bank and other development agencies, and the lessons learnt have been transferred to aquaculture, which is increasingly viewed as a “sunrise industry” able to meet the growing shortage of seafood. There is recognition now in many countries in sub-Saharan Africa that sustainable aquaculture must rely on the private sector and the risk-adjusted profit motive, rather than subsistence farming. There has been an encouragement of aquaculture small and medium enterprises (SMEs) and in certain countries, a better enabling environment. In the Americas, Canada has attempted to reduce the regulatory burden facing potential and actual aqua-farmers, and Chile, which has suffered from disease challenges, is developing legislation that will improve protection of the environment. It is important that the working conditions of salmon workers and the enforcement of labour standards will be included. In Asia, countries such as Viet Nam have adopted aquaculture as an engine of economic development. Regulations were established to improve fish quality, and incentives are offered to domestic and foreign investors to encourage investment. Specific funding has been allocated for research priorities such as mariculture and for sending students overseas for aquaculture education and training.

Among the strategies advocated in the Bangkok Declaration is greater stakeholder involvement. As mentioned above, in Thailand and elsewhere, hierarchical governance is giving way to more participatory forms, which is in line with the Bangkok Declaration that “improving co-operation amongst stakeholders at national, regional and inter-regional levels is pivotal for further development of aquaculture” (NACA/FAO, 2000: 2.16).

Similarly, the Bangkok Declaration urges “organisations and institutions representing the private sector, NGOs, consumers and other stakeholders” to be involved in order to make institutional capacity more effective. This has increasingly become the norm worldwide. For example, producers are involved in managing the “bay system” in New Brunswick, Canada and co-operate in husbandry operations in Scotland. The same occurs in Norway because self-management and co-management reduce the burden of regulatory enforcement. NGOs are active watchdogs over ecological developments in British Columbia, Canada and over ecological and labour conditions in Chile. Consumers are the ultimate arbiters of responsible aquaculture because they influence import certification through retail establishments, which may cease selling questionable products, as occurred with Chilean salmon in the United States of America. Demand for aquaculture products appears generally good, but consumers now have a constant source of information or misinformation, and their reaction can adversely affect demand very severely. Local communities are often involved in siting decisions, and consultation is critical if zoning and ICZM are to be effective.

The strategy of “developing, through a participatory approach, comprehensive and enforceable laws, regulations and administrative procedures that encourage sustainable aquaculture and promote trade in aquaculture products” has been less successful. An illustration of this failure is seen in the Chilean ISA crisis and the fines levied against salmon companies there for violations of the labour code. With licences granted in perpetuity, with market governance aimed at keeping costs to a minimum to gain competitive advantage, and with weak enforcement, salmon farming in Chile ceased to be environmentally and socially (and perhaps even economically) sustainable. Weak enforcement has resulted in heavy losses of Atlantic salmon (*Salmo salar*), several deaths (of divers) and numerous violations of International Labour Organization (ILO) labour standards (Pinto, 2007).

There are limits to participation, mostly due to scarce resources. Participatory methods involve expenditure of money, time and skills. In particular, the absence of long-term funding for participation has handicapped the credibility and effectiveness of coastal planning in Europe (Stead, 2005). Time constraints will also determine the extent of participation. Methods for participatory governance have different cost-efficiency and have been used. Two methods of particular interest are the Analytic Hierarchy Process (AHP) (Cai, Leung and Hishamunda,

2009) and the Delphi method (Hishamunda, Poulain and Ridler, 2009). Both have been applied to analyze a number of aquaculture issues, including criteria for aquaculture sustainability, the constraints on capital-intensive polyculture and developing aquaculture plans (e.g. in Chile).

Another strategy that has developed in aquaculture governance and was advocated in the Bangkok Declaration is the increased use of incentives: “incentives, especially economic incentives, deserve to be given more attention in the planning and management of aquaculture development”. Self-regulation and codes of conduct, whether at the local, national or regional level, use peer pressure and the threat of exclusion to induce responsible behaviour.

Many countries have adopted the Bangkok strategy of “developing a clear aquaculture policy, and identifying a lead agency with adequate organisational stature to play a strong co-ordinating role”. The 2008 “FAO Expert Consultation on Improving Planning and Policy Development in Aquaculture” reiterated the importance and role of a lead agency for aquaculture (FAO, 2008a). While certain lead agencies, such as INCOPESCA in Costa Rica and DIGEPESCA in Honduras were established prior to the Bangkok Declaration, others, such as INAQUA in Mozambique were established more recently. As suggested in the Bangkok Declaration, their role is to integrate aquaculture policy horizontally and vertically.

The Bangkok Declaration also stated that “the collection and dissemination of accurate and verifiable information on aquaculture may help to improve its public image and should be given attention”. Yet, in many countries, data collection is often overlooked, is incomplete or otherwise unreliable due to inadequate quality assurance/quality control, and typically lacks any form of independent audit to validate outputs. To develop a robust database requires planning (FAO, 2008a). The method of collection will depend in part on trust and on resource availability. There may also be a comparison of cost-effectiveness between methods (e.g. between enumeration and sampling). Southeast Asia provides an illustration of different collection processes (Hishamunda *et al.*, 2009a). In some countries, such as Cambodia and Costa Rica, producers are required to record information and pass this on to the authorities. While this individual reporting may be relatively inexpensive, concern by farmers over tax repercussions can reduce compliance. It can also result in deliberate inaccuracies.

As recognized in the Bangkok Declaration, research and dissemination of research results are an integral part of aquaculture governance. “There is a need to increase investment in aquaculture research, whilst making efficient use of research resources.” This was reiterated in the Norwegian strategy: “Experience from salmon farming has shown that research is decisive for a profitable and sustainable development” (Norwegian Ministry of Fisheries and Coastal Affairs, 2008). In Norway, the aquaculture industry funds mostly applied research,

leaving basic research predominantly to universities (Norwegian Ministry of Fisheries and Coastal Affairs, 2008). In the Philippines, demand-driven research was encouraged by private-public research partnerships (Hishamunda *et al.*, 2009a). Such private-public research has also been successful in Canada, where broader research in aquaculture was encouraged with a federal research programme, AquaNet, which only funded projects that were multidisciplinary. Efficiency of research can also be enhanced by collaboration among national and regional institutions. Collaboration diminishes duplication and encourages specialization, particularly if there is co-ordination of research efforts, perhaps by a lead agency.

Once the research results are known, it is important that they be widely disseminated. In India, the Farmers Training Centres not only disseminate technology to farmers, but also provide a communication channel to the researchers about field problems and indigenous technical knowledge.

Although perhaps not explicitly recommended in the Bangkok Declaration, a recent trend in aquaculture governance over the last decade is the increasing consideration of ecological sustainable development (ESD) principles and the associated use of risk-based aquaculture management planning involving expert panel-based risk analysis and decision support systems. There are many examples of this approach in Australian aquaculture, for example, in prawn aquaculture (DOF, 2009). In Canada, risk analysis is used by the lead agency for aquaculture, the Department of Fisheries and Oceans, in managing coastal allocation. Its advantages are that there is a common language and understanding of ecosystem effects of certain activities and that it can guide appropriate mitigation measures.² There are four stages in risk analysis. The initial stage is assessment, which is the identification of risks. It is followed by the analysis of risks and their measurement. The third stage is risk response, which may require mitigation. The last step is risk communication.

While beneficial in providing a scientific basis for the assessment of potential hazards, risk analysis can be problematic at the policy level. In some cases, probabilities are unknown, and the danger is that there could be heavy economic and social impacts of disallowance. The opportunity costs of lost incomes or abandoned communities may not be considered in the scientific analysis. A final caveat is the communication of risk. Its scientific context may not be understood by the public, for whom the concept of risk is very negative; poor communications can create mistrust for aquaculture activities and for farmed fish (Mazur and Curtis, 2008).

² Source: presentation given by I. Burgetz on *Ecosystem based approaches to environmental interactions of marine aquaculture: a Canadian perspective*, PICES 17th Annual Meeting October 24 – November 2, 2008, Dalian, PR China (available at: www.pices.int/publications/presentations/PICES_17/Ann2008_S5/9_s5_Burgets.pdf).

Expectations regarding aquaculture governance in the future

Governance will become more important, with jurisdictions ambitious to develop aquaculture adapting “best practices” from elsewhere. With its successful expansion of salmon farming without major environmental or social challenges, Norway appears to be a model. It has a dedicated aquaculture law focused on economic interests but subject to sustainability constraints. This economic orientation is reflected in its ambition to simplify administrative and regulatory procedures so as not to penalize producers and jeopardize comparative advantage. Licensing procedures meet the four governance principles suggested earlier; plus, they are constantly evolving and improving. Participation of local communities is necessary because they decide on siting.

There will be dissemination and adoption of best practices such as these. There will also be more emphasis on pre-appraisal of regulations, as countries will strive to avoid over-regulating aquaculture; over-regulation has been an alleged deterrent to investment in aquaculture in some countries, including Canada. Not only may over-regulation be a disincentive to investment, it may also result in lack of enforcement. All jurisdictions find monitoring and enforcement costly; regulations that cannot be enforced undermine legislative credibility.

Social acceptability, also known as social license, is an integral part of sustainability. Yet, it has usually become an issue for aquaculture planners only after sections of the population have demonstrated discontent through conflicts, boycott or litigation. While aquaculture can contribute to economic growth, it can also create social disruption and inequities. Jealousy, concern over resources and resentment over hiring practices may trigger social conflict, as with shrimp farming in parts of South Asia. This can be particularly acute if small elites, domestic or foreign, dominate the industry.

Policy-makers must be aware of perceptions towards aquaculture that are often negative. The repercussions for aquaculture development can be severe, as demonstrated by opposition to site licenses for salmon farming along the west coast of Canada. This kind of attitude towards aquaculture is likely to continue or even become more severe. As mentioned above, respondents to a global Delphi survey expected public opposition to aquaculture to be “very detrimental” to aquaculture development in North America to 2020 (Hishamunda, Poulain and Ridler, 2009). In the same survey, respondents from Asia and Western Europe were also concerned about “social opposition to aquaculture due to sensationalist media”.

Too often, communications have been ignored or down-played by the aquaculture industry and by governments, leaving NGOs alone to dominate the media. This can have deleterious consequences. If food safety concerns become an

issue, demand for farmed fish, which appears to be generally strong, suffers. An example was the refusal of Safeway in the United States of America to sell salmon from Chile following a report in the New York Times in March 2008 about excessive use of antibiotics.

Concerns about fish quality standards and the manner in which fish is produced reflect a matter of trust. In some instances, public mistrust of aquaculture is demonstrated by legal challenges to site allocation, by pressure put on politicians to declare moratoria on aquaculture expansion, or even by vandalism. A study of Canadian attitudes towards aquaculture, particularly salmon cage culture, illustrates how opinion can impact decision-makers (DFO Canada, 2005). In British Columbia, Canada, perceptions of focus groups were almost uniformly hostile to aquaculture, largely because of ecological concerns. The result has been such vigorous opposition to aquaculture siting that a moratorium on new sites was imposed in 1995 (Galland and McDaniels, 2008); it was only lifted in 2002. The report concluded that the public wanted reassurance about the environmental risks of cage culture, and from a credible source.

To counter public opposition, there must be more transparency and less secrecy on issues such as fish health and pollution. Information on escapees, on diseases and on any health risk must be provided to governments, who could then disseminate it to the public. There should also be pro-active media communication strategies. Countering public opposition could also be achieved by informing the public with campaigns about all aspects of aquaculture, ensuring that sound information is available from credible sources and using the Internet for two-way information sessions. Widespread participation in aquaculture planning also induces trust in the industry (Mazur and Curtis, 2008).

Emerging issues in aquaculture governance

Endogenous factors

Aquaculture governance is likely to become ever more important in the future if the sector is to remain sustainable. This is because all four factors of sustainability – economic, environmental, social and technical – will face challenges. Some of the likely challenges that are intrinsic to the industry as it grows include the emergence of oligopolies in the production of certain species, the dominance of individual monopsonists in local communities, reconciling competing claims to water and land, the need to manage aquaculture within a deteriorating ecosystem, vocal opposition from well-funded NGOs and funding of local research.

Industrial concentration is an endogenous issue that is emerging for farmed species which are global commodities and whose production is capital-intensive and therefore susceptible to economies of scale. An example is farmed salmon, where consolidation has occurred through bankruptcies and mergers. In 1996, about 114 farms produced 80 percent of the world supply of farmed salmonids.

By 2006, the number of farms producing 80 percent of the world supply had fallen to 46 (Marine Harvest, 2008).

The concentration ratio (the proportion of the four largest farms in total national production of farmed Atlantic salmon) in Canada in 2006 was 92.3 percent; three farms alone produced 90 percent of output (Marine Harvest, 2008). This concentration ratio is higher even than in the United Kingdom (88.6 percent) and appreciably higher than in Norway (47.4 percent) and Chile (44.2 percent). In Canada, two firms, Marine Harvest and Mainstream, dominate production on the west coast, with Marine Harvest alone accounting for about half the production.

With concentration has come foreign ownership. Globally, two transnational companies, both based in Norway, dominate salmonid aquaculture. The most important is Marine Harvest. It has operations in Norway, Chile, Scotland, Canada, Ireland and Denmark (the Faroe Islands); in all these countries, it is the single largest producer. It produced about 380 000 tonnes of salmonids in 2006, of which 358 800 tonnes were Atlantic salmon (more than one-quarter of world output). It is a major fish processor, with European plants in Belgium, Spain, France and the Netherlands. The second major transnational company is Mainstream, whose holding company is Cermaq. The principal shareholder is the Norwegian Government, with 43.5 percent of the capital. It is the third-largest producer in Chile and the second-largest in Canada's British Columbia. The Cermaq group includes the world's largest feed manufacturer.

Diversifying geographically to different countries, as Marine Harvest and Mainstream have done, is a rational strategy for farms. Diversification reduces disease risk and economic risks due to exchange rate volatility (Ridler *et al.*, 2007). However, there are dangers to communities reliant on a single employer, particularly one which is foreign. If there is a negative shock to the market, a dominant company can demand environmental or wage concessions. If foreign, the company may have little commitment to the community if unsatisfied. How responsible the company feels to its employees (stakeholders) as well as its owners (shareholders) depends on its commitment to social responsibility and corporate governance, but the danger of regulatory abandonment exists. As concentration in aquaculture continues and even accelerates, this issue will also be one for aquaculture governance in general.

Currently, most aquaculture operations occur in areas under the sovereignty or national jurisdiction of the coastal state (internal waters, archipelagic waters, territorial sea, contiguous zone, exclusive economic zone (EEZ) and the continental shelf). Although they might be weak and their enforcement imperfect, legislative and regulatory frameworks that govern aquaculture in these waters exist in most aquaculture-producing countries.

With the growing scarcity of land available for fish farming in most countries around the world and the escalating shortage of freshwater, the majority of aquaculture expansion in the coming decades is likely to occur in seas and oceans. With improved technology, sophisticated culture systems will induce a movement away from inshore to deeper offshore waters. These waters could be within the EEZ of countries, or even further, beyond the 200 mile belt of national jurisdiction. In 2009, Marine Harvest announced plans for four new offshore sites in the United Kingdom, each farm producing 20 000 tonnes of salmon.

As aquaculture expands offshore, the problem of farming in an environmentally and socially responsible manner will become more challenging. Governance will be of a critical importance in ensuring that any expansion of the industry occurs on socially responsible principles. For example, when sites are located some hours from shore, workers may be paid only when they arrive on site rather than from the time they depart. This issue has arisen in Chile. In order that offshore aquaculture can be sustainable, administrative and regulatory frameworks will have to be developed, even for aquaculture within the EEZ (USDC, 2008).

Aquaculture will compete with other activities, particularly those related to the utilization of living and mineral resources, and to navigation and communication. Thus, one of the biggest challenges facing policy-makers is to establish international policy, institutional, legal and regulatory regimes for use to govern aquaculture operations that occur in waters that are beyond national jurisdiction. There is no clear regulation of mariculture on the high seas, which suggests that if mariculture extends from a state's EEZ to the high seas (or even beyond the territorial sea in the case of the Mediterranean), there will be a regulatory vacuum. The challenge will also be to have these regimes address the shortcomings commonly found in the national schemes.

Exogenous factors

In addition to factors that are inherent and/or endogenous to aquaculture, there will be exogenous shocks. Because of environmental repercussions and trade, aquaculture is a sector that is vulnerable to wider global and regional shocks. Hence, aquaculture governance cannot be divorced from international and inter-regional influences. Among these shocks are the growing role of the retail sector in dictating standards, the public's increasing interest in food safety and the environment, climate change and the spread of animal diseases, and financial imbalances resulting from the global recession. The latter could threaten public funding of aquaculture research and limit the ability of producers to access credit from financial institutions.

The issue of the role of the retail sector in dictating standards and the public's increasing interest in food safety and the environment impact on trade. Domestic and international trade are globalizing hygiene and traceability standards, obliging governance of aquaculture to adapt. Globalization of food chains,

expansion of supermarkets' standards and the World Trade Organization (WTO) require increased traceability, ecological sustainability, and health and safety certification. Domestic consumers are also more demanding. There is growing legal pressure on companies to demonstrate due diligence in food risks, and a certain sense of corporate social responsibility. Carrefour, for example, sends inspectors on a regular basis to producers and processors to ensure that they satisfy its 85 page manual (Phyne, Apostle & Horgaard, 2006). The gatekeeper for checking quality can be a certifying body or perhaps a supermarket chain, rather than a competent authority overseeing international trade. However, the effect is similar, because it obliges producers to ensure traceability and meet consumer demands for environmentally responsible production (Ababouch, 2008).

There is a danger that private certification schemes could duplicate government standards, adding compliance costs to farmers, particularly small-scale farmers. Consumer concerns about human and animal health, safety and environmental sustainability drive changing and more demanding standards; NGOs compound them. They have already obliged retailers in some importing countries to demand standards through the supply chain. Certification raises concerns about protectionism and whether private certification complies with the WTO's Agreement on Sanitary and Phytosanitary Measures. Aquaculture in developing countries is particularly vulnerable. Compliance for developing countries can be very difficult, jeopardizing their export opportunities (Bagumire, *et al.*, 2009).

As the FAO "Technical Consultation on the Guidelines on Aquaculture Certification", which was organized in Rome in February 2010, demonstrated, FAO Members show an increasing interest in the certification of aquaculture systems, practices, processes and products, and are striving to improve responses to these concerns, assure consumers and secure better market access. However, certification will remain an issue for some years ahead. In this context, the role of value chains and the cluster-based approach to development and adoption of BMPs by smallholder producers is particularly relevant.

A future global shock to aquaculture governance could come from climate change and weather uncertainty (FAO, 2008b). Some effects may be beneficial. Growing periods could shorten, with improved growth rates and feed conversion rates. However, many effects will be negative, particularly as most aquaculture is in tropical and subtropical Asia. There could be increased virulence of pathogens and animal diseases, reduced ecosystem productivity in warmer waters and adverse impacts on livelihoods (Soto and Brugere, 2008). Sea-level rise would damage onshore facilities and cause salt-water intrusion, while extreme weather conditions cause destruction of cages, with escapees, possibly leading to loss of biodiversity. Good governance is essential to facilitate strategies designed to adapt to and/or mitigate the effects of climate change in aquaculture.

At the regional level, climate change and extreme weather could reinforce regional institutions and structures (FAO, 2008a). There may be regional co-operation in areas such as the gathering of common data and the sharing of best practices, as well as in the control of fish diseases and the introduction of exotic species. Climate change, therefore could reinforce regional governance of certain issues in aquaculture. Increased supply volatility and the need to reduce carbon footprints could oblige individual producers to review supply chains and distribution outlets, which would encourage more local trade, perhaps at the cost of global trade in commodity species such as salmon; for example, the transport of 1 kg of salmon 7 000 km from Chile generates 8.2 kg of CO₂ (Valenzuela, 2009).

The way forward

Aquaculture governance remains an issue in many countries where there are still conflicts over marine sites and preventable disease outbreaks. In addition, in certain countries, there is still widespread public mistrust of aquaculture, particularly marine cage culture; another indication of poor governance. The lack of development of aquaculture in certain jurisdictions, in spite of favourable demand and supply conditions, may also be a reflection of poor governance.

While several countries have made commendable efforts to set up policies, administrative, legal and regulatory frameworks to properly manage aquaculture, there is evidence that such efforts could be particularly hampered by the lack of financial and skilled human capacity to establish, enable, monitor and enforce regulations. Policies and regulations may be enacted, but unless there are sufficient government personnel with adequate skills and financial resources to monitor and enforce them, they will remain ineffective. The lack of resources for monitoring and enforcement may be as critical as the absence of laws or regulations. This issue needs to be tackled if aquaculture governance is to improve.

There is also a need to continue empowering local communities in aquaculture governance and to improve collaborative management. In many places, dialogue between the public and the production sectors is poor, and when it occurs, it is often biased towards big businesses at the expense of small-scale farmers and the rest of the community. It is therefore important to improve dialogue among farmers themselves, especially the resource-poor small-scale farmers, and to empower them to compete in the market. Assisting farmers to organize themselves into “clusters” or farmer associations and building their capacity to better manage their farming practices has proven beneficial, particularly in the shrimp sector. This practice could be encouraged further in other sectors as well.

An important means of easing many of these concerns could be to collect and disseminate positive and negative experiences in aquaculture governance

and to elaborate and disseminate “Technical Guidelines on Aquaculture Governance”. The purpose would be to assist developing countries in setting up good governance practices based on lessons learnt elsewhere. A special focus could be placed on mariculture governance.

Conclusions

One of the major determinants of successful aquaculture is governance, which includes not only the means of managing the industry but also the process by which decisions are made and implemented. Processes vary with traditions and values, which precludes a universal template, but there are enough common features for an overall guide.

One feature is the common goal of aquaculture governance: its sustainability. Sustainability requires profitability consistent with all risks associated with aquaculture, and environmental neutrality, so that ecological impacts are mitigated. It also entails social acceptability of the industry. To achieve this goal of sustainability, four governance principles are proposed: accountability, effectiveness and efficiency of government activities, equity and predictability.

Another common feature of successful aquaculture governance is an enabling environment. An enabling environment implies the rule of law and the secure right of property. Contracts must be enforceable, theft and corruption must be punished, and farmers must be convinced that all outputs resulting from their efforts and expenditures will accrue to them rather than be siphoned off. An enabling environment also needs economic and social stability. Uncertainty is an anathema to investors, so governments must reduce risks and transaction costs where possible. Exchange rate stability, low inflation, a minimum of regulation and lack of violence are fundamental.

Strategies to increase predictability, such as zoning and ICZM, also reduce risk and transaction costs. Participation appears to be effective, particularly if the producers are included. Self-regulation by the industry empowers producers to pressure those who are reluctant to comply, thus encouraging wider compliance and reducing costs of enforcement. Wider participation by the public is also useful for zoning and ICZM strategies because interests are then explicit early in the spatial planning process. This obviates conflicts during siting decisions.

Governance will become increasingly important as aquaculture expands in an environment of deteriorating ecosystems, vocal and well-funded NGOs, climate change, consumer concerns over food safety and the environment, and internationalization of regulations due to import requirements. The industry will become more concentrated for those species which are global commodities, with oligopolistic, even monopolistic structures. This may create resentment, particularly if the dominant firms are foreign-owned. Trust in the industry will

be critical to maintain social licence, which will oblige governments and the aquaculture industry to increase transparency and to improve communications.

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Review on aquaculture's contribution to socio-economic development: enabling policies, legal framework and partnership for improved benefits

Expert Panel Review 2.2

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Abstract

The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 recognized that aquaculture contributes greatly to people's livelihoods, food security, poverty alleviation, income generation, employment and trade; and that the potential of aquaculture's contribution has not yet been fully realized across all continents. It also recognized that the potential of aquaculture's contribution to human development and social empowerment cannot be fully realized without consistent, responsible policies and goals, effective institutional arrangements and regulatory frameworks, and improved co-operation among stakeholders at the national, regional and inter-regional levels. It suggested that the aquaculture

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sector should continue to be developed towards its full potential of contributing towards sustainable livelihoods, human development and social well-being.

Through innovations in technology and organization, intensification in operations, and diversification in products, species and culture systems, aquaculture continues growing in the new millennium towards a matured and global industry, accounting for half of the world seafood supply and with a large portion of its products traded across borders. While the sector is still mainly motivated by and promoted for its economic benefits, increasing attention has been paid to aquaculture's environmental and social responsibilities. Learning from past experience of runaway yet unsustainable aquaculture growth, regulations and public policies have been used to establish clear guidelines for resource utilization and promote sustainable practices in aquaculture operations. Public concerns over aquaculture's environmental and social impacts have become more influential through certification schemes initiated by advocacy groups or private entities. Fish farmers have become increasingly aware of the importance of long-term sustainability and more willing to adopt codes of conduct, best management practices (BMPs), farmers groups and other self-discipline mechanisms. In short, the main themes of aquaculture development in the first decade of the new millennium are sustainable economic growth, environmental stewardship and a pro-poor orientation.

Despite the progress made, institutional arrangements for sustainable aquaculture development have only made baby steps and have many aspects to improve. Even though impressive aquaculture development has made the sector increasingly recognized as more than just a branch of fisheries, most countries still lack laws and regulations specifically designed for aquaculture; and thus the sector has to deal with diverse regulations designed by different agencies, probably without consideration of the situation of aquaculture. Even with laws and regulations specifically targeting aquaculture, lack of institutional and human capacity for implementation may render them ineffective. While certification schemes have helped facilitate environmentally and socially responsible behaviours, their proliferation has caused confusion, increased costs of compliance and fostered cynicism that these schemes are no more than marketing trickeries for higher profit margins. Despite increasing awareness, knowledge and technical constraints tend to hinder aquaculturists' attempts to fulfill their environmental and social responsibilities.

In light of this, this paper reviews the socio-economic impacts of aquaculture based on recent experience and discusses how institutional arrangements can facilitate positive development and mitigate negative impacts.

KEY WORDS: *Aquaculture, Legislation, Policy, Socio-economic development, Sustainable aquaculture.*

Introduction

The *Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (NACA/FAO, 2000) recognized that aquaculture has made a great contribution to people’s livelihoods, food security, poverty alleviation, income generation, employment and trade; and that aquaculture’s contribution to human development and social empowerment cannot be fully realized without consistent, responsible policies and goals, effective institutional arrangements and regulatory frameworks, and improved co-operation among stakeholders at the national, regional and inter-regional levels. The Bangkok Declaration suggested that aquaculture policies and regulations should promote economically viable, environmentally responsible and socially acceptable farming and management practices so as to help the sector develop towards its full potential of contributing towards sustainable livelihoods, human development and social well-being.

Through innovations in technology and organization, intensification in operations and diversification in products, species and culture systems, aquaculture continues growing in the new millennium towards a robust and global industry. The total world aquaculture production reached 68 million tonnes in 2008, which is 64 percent higher than the 2000 level.¹ The share of aquaculture production (measured by weight) in the total fisheries production (including both capture and culture products) has increased from 31 percent in 2000 to 43 per cent in 2008.² Approximately 32 million tonnes of seafood (worth USD 94 billion) were traded internationally in 2007, which was 20 percent higher than the level in 2000 (nearly 70 percent higher in terms of value).³ In 2006, there were nearly 8.7 million people engaged in fish farming globally, which was 13 percent higher than the number of aquafarmers in 2000 (FAO, 2009).

While negative environmental impacts were a major liability to its public image, aquaculture development in the new millennium has become more resource conserving and environmentally friendly, thanks to more stringent public scrutiny and innovations in farming technologies and practices. For example, restrictive public regulations have been established in most countries to mitigate aquaculture’s negative impacts on natural habitats (e.g. mangroves);

¹ Aquaculture production of crustaceans nearly tripled during this period; and the growth for other major species was 86 percent for marine fishes, 70 percent for aquatic plants, 63 percent for freshwater fishes, 47 percent for diadromous fishes and 34 percent for molluscs.

² The shares of aquaculture in total fisheries have increased for all the species: aquatic animals (from 20 percent to 58 percent), aquatic plants (from 88 percent to 94 percent), crustaceans (from 22 percent to 46 percent), diadromous fishes (from 56 percent to 68 percent), freshwater fishes (from 72 percent to 76 percent), marine fishes (from 1.3 percent to 2.6 percent) and molluscscs (from 56 percent to 64 percent).

³ Approximately 70 percent of seafood traded across borders in 2007 was marine fishes, 10 percent was crustaceans, 9 percent was molluscscs, 7 percent was diadromous fishes, and 3 percent was freshwater fishes. The trade volume growth rates during the period were 270 percent for freshwater fishes, 56 percent for diadromous fishes, 52 percent for crustaceans, 24 percent for molluscs and 10 percent for marine fishes.

certification schemes (e.g. ecolabelling), which enable consumers to express their environmental concerns through market forces, have become increasingly popular; and environmentally friendly practices have been widely promoted within the private aquaculture sector through codes of conduct and better management practices (BMPs) (FAO, 2006; World Bank, 2006).

Increasing effort has also been spent to make aquaculture development more socially acceptable. The role of aquaculture in rural development has been increasingly recognized, and pro-poor has been widely accepted as a main objective of aquaculture development (World Bank, 2006; FAO, 2006, 2009). Almost all the aquaculture growth between 2000 and 2008 was attributable to aquaculture development in developing countries. While aquaculture production in developed countries increased by 7 percent during the period, the growth for developing countries was 70 percent. While half of aquaculture production came from low-income food-deficit countries (LIFDCs) in 2000, their contribution increased to 81 percent in 2008.

Seafood continues to be an important source of protein in the new millennium, contributing 16 percent of animal protein intake (10 percent of total protein) per capita per day in 2007. On average, each person in the world obtained 4.7 g of protein per day from seafood in 2007, which was 7 percent higher than the level in 2000 and 21 percent higher than that in 1990. For LIFDCs, seafood contributed 20 percent (or 25 percent for least-developed countries) of animal protein intake per capita per day in 2007; and each person in these countries on average obtained 3.9 g (or 2.7 g for least-developed countries) of seafood protein per day in 2007, which was 8 percent (or 17 percent for least-developed countries) higher than the level in 2000 and 56 percent (or 28 percent for least-developed countries) higher than that in 1990.⁴

In sum, aquaculture development in the new millennium has made progress towards the goal of being economically viable, environmentally responsible and socially acceptable. Improvement in institutional arrangements is a major contributing factor to this achievement: freer international market access has allowed countries to exploit their comparative advantages and gain from trade; more active public policies and stricter regulations have streamlined the allocation and management of common resources and promoted sustainable practices in aquaculture operations; various certification schemes have made the aquaculture production process increasingly accountable for its environmental and social impacts; and codes of conduct, farmers groups and other self-regulating mechanisms have fostered awareness of aquaculture's environmental and social responsibilities and corresponding modifications of behaviour. Despite the progress made, aquaculture development is expected to continue facing resource, environmental, economic, knowledge and institutional

⁴ These figures are calculated based on the FAO Food Balance Sheet.

constraints; and more efficient and effective institutional arrangements are needed to help the sector overcome them.

This paper reviews aquaculture’s socio-economic impacts and explores the role of institutional arrangements in promoting sustainable aquaculture. In the following sections, aquaculture’s socio-economic impacts are reviewed based on recent experience, and facilitating factors for positive impacts and mitigating measures for negative ones are discussed; institutional arrangements regarding aquaculture development are reviewed and their positive and negative roles in facilitating aquaculture’s socio-economic impacts are discussed. The paper concludes with some remarks on the way forward.

Socio-economic impacts of aquaculture

Aquaculture has profound socio-economic impacts. While aquaculture represents a potentially more efficient (than capture fisheries) way of utilizing natural resources to produce aquatic products for food, pharmaceutical, recreational and other purposes, imprudent aquaculture operations could cause environmental degradation, the socio-economic costs of which tend to outweigh the sector’s short-term benefits. While aquaculture generates incomes and stimulates local economic growth, aquaculture development may have negative impacts on other industries (e.g. agriculture, fisheries, tourism) because of its environmental externalities and due to resource competition. While rapid aquaculture expansion lowers the price of aquaculture products to the benefit of foreign consumers, domestic seafood producers may nevertheless become worse off. While aquaculture brings new opportunities (e.g. highly paid jobs, training, business opportunities) to the community, some stakeholders may become marginalized and worse off.

These are only a few examples of tradeoffs among aquaculture’s complex socio-economic impacts that will be reviewed based on countries’ recent experience in aquaculture development (FAO, 2006; World Bank, 2006). While there are potentially many ways to categorize aquaculture’s socio-economic impacts, this review groups them into environmental impacts, economic impacts and social impacts.

Environmental impacts

Aquaculture operations utilize land, water, wild species, fuel and other natural resources and interact with the surrounding biophysical environment. Sustainable aquaculture development requires the sector to be resource conserving and environmentally non-degrading (FAO, 1989). While aquaculture’s negative environmental impacts are often cited as evidence against its development (Allsopp, Johnston and Santillo, 2008), the sector has become more resource conserving and environmentally friendly in the new millennium, thanks to more active public resource management and stricter regulations, innovations in fish

farming technologies and practices, and improved awareness of aquaculture's environmental responsibilities in both the public and private sectors (FAO, 2006).

Habitat conservation

Unsustainable aquaculture practices tend to cause degradation of wetlands, lagoons, mangrove forests, seagrass habitats and terrestrial habitats. While one of aquaculture's most publicized negative environmental impacts was destruction of mangroves (GESAMP, 1991),⁵ such impacts have been mitigated in most regions, thanks to stricter regulations (use of mangroves for aquaculture is completely banned in some countries), better coastal planning and management measures (e.g. zoning, environmental impact assessment (EIA)) and more environmentally friendly farming technology and practices (FAO, 2006).

In general, awareness of the importance of habitat conservation has been growing, but more effort (e.g. improvements in siting approaches, farm construction and feed management) is needed to protect bottom ecosystems (e.g. coral reef and sea grass) from aquaculture's organic wastes, and freshwater marshes and wetlands from improper aquaculture practices (FAO, 2006).

Land and water

Land and water are two major natural resources essential to aquaculture. Aquaculture can provide environmental services by rehabilitating sodic lands, providing nutrient-rich mud to nearby agricultural land, and reducing nutrient load and heavy metal content in surrounding water through the farming extractive species such as molluscs and seaweeds (FAO, 2006; World Bank, 2006).

However, aquaculture wastes (effluent and sediments) from intensive use of artificial feeds and chemicals (i.e. medicines, disinfectants and antiseptics), if not properly handled, could cause land salinization, eutrophication, algal blooms, chemical pollution and other environmental degradations (STREAM, 2003).⁶ Such negative environmental impacts have not only caused conflicts between aquaculture and other sectors,⁷ but also contributed to its own disruption, because poor farming environment is a recipe for low yield and

⁵ For example, unbridled expansion during the early stage of aquaculture development in Thailand destroyed 25 percent of the country's mangroves forest (GESAMP, 1991). Mangrove conversion for aquaculture in Ecuador and many Southeast Asian countries has caused soil and groundwater salinization and disrupted the livelihoods of local communities (GESAMP, 1991; Sathirathai and Barbier, 2001; Barbier and Cox, 2004).

⁶ For example, concentrated shrimp farming activities have led to eutrophication and frequent phytoplankton blooms in Mexican coastal marine waters (Cruz-Torres, 2000). Excessive use of CuSO₄ for curing shrimp diseases has caused extremely severe pollution in the water of the Pearl River Delta in China (IISD, 2004).

⁷ For example, conflicts among shrimp farmers and confrontations between shrimp growers and other local farmers and residents occurred in Thailand because of the discharge of effluent water into public waterways and coastal areas, the intrusion of saline water into rice fields and the salinization of canals (Jenkins *et al.* 1999; Be, Dung and Brennan, 1999). Similar conflicts between corporate shrimp farmers and fisherfolk also occurred in India (Bhat and Bhatta, 2004).

disease outbreaks. Restricting areas for aquaculture activities through zoning, requiring EIA as a precondition for granting aquaculture licenses or permits, and promoting BMPs in aquaculture operations have been used to reduce aquaculture’s negative impacts on surrounding environment (FAO, 2006; World Bank, 2006).

Aquaculture development competes with other activities (e.g. fisheries, agriculture, livestock farming, woodcutting, fuelwood gathering, recreation, settlement and conservation) for natural resources (Barraclough and Finger-Stich, 1996; FAO, 1997; Flah Vandergeest and Miller, 1999).⁸ As a new and less-established industry, aquaculture is sometimes not given high priority in allocation of common resources and is subject to high environment protection standards. Use of land and water for aquaculture has been restricted through land use planning and zoning (e.g. in Chile, Mexico and China); and environmentally degrading practices (e.g. using freshwater for salinity control and extracting underground water) strictly regulated (FAO, 2006). Under this situation, resource-conserving aquaculture practices have been adopted; examples include using land unsuitable for other purposes, rotating use of land for agriculture and fish farming, integrated agriculture and aquaculture operations (e.g. rice-fish farming) and using recirculation or closed-water systems, among others (FAO, 2006).

Wild species

Aquaculture can help preserve wild fish stocks by supplying more affordable aquatic products and hence reducing the pressure on fisheries (Tisdell, 2004). Aquaculture can also increase wild fish stocks through restocking programmes (Petr, 1998). However, environmental degradation caused by aquaculture may negatively affect wild species. In addition, collection of wild seed and broodstock, introduction of exotic species and aquaculture escapees may also have negative impacts on wild stocks (FAO, 2006; World Bank, 2006).

Most aquaculture species still rely on wild stocks for seed or broodstock. As collection of wild seed and broodstock tends to damage not only the targeted wild stocks but also those of bycatch species,⁹ increasing public concerns over biodiversity have put it under stricter scrutiny and regulation; some countries (e.g. Egypt) have established official fry collection centers or have used licensing to regulate such activities (FAO, 2006). However, because in some countries wild seed and broodstock collection is a lucrative business providing the livelihoods for many low-income people, public attempts to restrict it tend to be difficult because of social pressure, or they may not be effective because of black markets (FAO, 2006).

⁸ A survey on shrimp farming in Thailand found that 49 percent of the land used by shrimp farms was previously rice fields and 27.5 percent used to be orchards (Jenkins *et al.*, 1999).

⁹ Confrontations have occurred in Mexico between fishermen and shrimp farmers over collection of shrimp larvae (Cruz-Torres, 2000).

Advances in artificial breeding technology have helped reduce aquaculture's dependence upon wild seed resources for an increasing number of species (milkfish, tiger prawn, mangrove crabs, etc.). One notable achievement is success in hatchery-breeding specific pathogen free (SPF) whiteleg shrimp (*Litopenaeus vannamei*), which has led to a big leap forward of the shrimp farming industry in the new millennium. The scarcity of seed resources is expected to continue driving progress in artificial breeding through the market mechanism, while more public supports and better partnership between scientific researchers and the private sector are needed to speed up the process (FAO, 2006).

Other controversial issues include the introduction of exotic species and aquaculture escapees, which may negatively affect wild stocks through habitat competition, disease spread and gene contamination (APEC/FAO/NACA/SEMARNAP, 2001). Genetic resource management (e.g. selective breeding, hybridization, chromosome-set manipulation, genetic engineering) is a common practice in aquaculture, which has significantly improved the productivity of farmed species (FAO, 2006). However, such farmed species, once let into the wild environment, may intrude genetic integrity and cause ecological disruption (Naylor *et al.*, 2005). While the damaging impacts of farmed species in the wild are not entirely clear, public concerns over biodiversity and biosecurity have led to stricter regulations (e.g. requirement of import risk assessment) prior to introducing new species or strains for aquaculture (FAO, 2006, Arthur *et al.*, 2009). Various measures (e.g. removal of escapees as a precondition for farm licenses, selecting sites with least impacts on wild stocks, promoting aquaculture practices that prevent escapes) have been applied to reduce the impacts of farmed species on wild stocks; further studies on the impacts of cultured species on biodiversity are needed (World Bank, 2006).

Energy

Although many aquaculture operations (e.g. pumping, water circulation, aeration, lighting, transport, refrigerating) require energy, energy consumption in aquaculture has received relatively little attention. However, this situation may change soon, as energy prices have increased substantially. Intensive aquaculture has been promoted to conserve natural resources, but as intensive operations (e.g. water recirculation systems) tend to be highly energy consuming, the tradeoffs between reducing aquaculture's direct environmental impacts and increasing its indirect impacts (through using more energy) need to be evaluated (e.g. through full life-cycle analysis) to determine whether intensive operations are more environmentally friendly than extensive aquaculture (FAO, 2006).

Economic impacts

While initially being promoted as a supplemental activity to agriculture for enhancing food security and providing extra cash to rural farmers, aquaculture has now developed into a highly commercial business in some places, accounting for nearly half of world aquatic product supply and with a large portion of its products traded across borders (FAO, 2009).

Contribution to economic growth

Aquaculture contributes directly to economic growth by providing wages and jobs to workers, profits to business owners and tax revenues to governments, as well as foreign exchange. Aquaculture development also induces income and employment generation in downstream industries (e.g. fish traders, seafood processing plants, supermarkets, restaurants, pharmaceutical companies) and upstream industries (e.g. seed collectors, hatcheries, feed producers). Increases in household, business and government incomes from aquaculture development would further stimulate the local economy through consumption, investments and government programmes. Aquaculture development would also tend to facilitate development of infrastructure and financial institutions, which would become public goods beneficial to the entire community (Hishamunda, Cai and Leung, 2009). Aquaculture’s contribution to economic growth is one of the reasons why experts think aquaculture should be encouraged (Hishamunda, Poulin and Ridler, 2009).

While aquaculture has greatly increased its economic contribution in the new millennium (FAO, 2009), it is still a less-established sector than fisheries or agriculture. However, aquaculture’s various economic linkages can make it a key sector and engine of growth for communities with comparative advantages in aquaculture. Examples include salmon farming in Chile and shrimp farming in Thailand, Ecuador and Madagascar (FAO, 2006). Unfortunately, aquaculture’s linkage impacts are usually difficult to quantify because of lack of data and systematic knowledge about the sector’s economic linkages to the economy, which tends to result in underestimation of aquaculture’s contribution to economic growth. Indeed, even the measure of aquaculture’s direct contribution to value added needs improvement. While aquaculture’s production value is commonly used to gauge its contribution to gross domestic production (GDP), the measure may not be accurate because production value tends to be influenced by value added belonging to foreign countries (e.g. the value of imported feed), as well as non-market forces such as subsidies. As aquaculture’s economic contribution is important information needed by policy-makers to determine the allocation of public resources, further research in this area is warranted.

Impacts on other industries

Aquaculture tends to compete with other sectors for natural resources, human resources, financial resources, government funding, markets, etc.; and its environmental externalities may negatively affect other sectors. Thus, rapid aquaculture development has led to conflicts between aquaculture and other sectors (FAO, 2006).¹⁰ While aquaculture’s negative externalities should be reduced to a minimum by integrating aquaculture into the entire economic development plan, it should be realized that competition among sectors is

¹⁰ For example, conflicts occurred between aquaculture and tourism/recreational activities in the Mediterranean and Adriatic seas, and with small-scale fisheries in Latin America (FAO, 2006).

inevitable and may actually be a positive factor because resources should be allocated to more efficient sectors, and the development of these sectors would stimulate economic growth that benefits all the sectors.

A case in point is the relationship between aquaculture and fisheries. While aquaculture is often viewed as a competitor of fisheries, the great potential in seafood demand actually allows aquaculture to be a complement to rather than a substitute for fisheries. Aquaculture development can benefit the fisheries sector by increasing demands for fisheries products (e.g. fishmeal and fish oil as feed ingredients), enlarging the market base for seafood and perhaps creating a niche for captured products, reducing costs of seafood processing and marketing, and motivating the fisheries sector to be more efficient (Anderson, 2007).

However, in the short run, policy-makers have to determine how to distribute limited public resources efficiently. Such decision-making requires information about the country's or region's comparative advantages in different sectors. Unfortunately, such information is rarely available because of lack of research in this area.¹¹ This makes it more difficult for aquaculture, as a latecomer, to compete with established sectors for public resources.

Competition within aquaculture

Aquaculture has become an increasingly commercial business in the new millennium. While freer market access gives countries opportunities to gain from their comparative advantages in aquaculture, it also increases the level of competition in the sector, which has resulted in significant price decline in many cultured species such as carps, tilapia, shrimp, salmon and Japanese eel (FAO, 2006).

While competition is a positive factor that benefits consumers with lowered prices and motivates technological advances, species diversification, new markets and quality improvement (FAO, 2006), harsh competition may disrupt the industry and cause serious damages in the short run, especially when fish farmers, under the pressure of low profit margins, choose to adopt unsustainable farming practices (Bai, 2008).

Competition has also led to trade disputes.¹² Seafood exporting countries (mostly developing countries) complained that importing countries (mostly developed

¹¹ While there are a few studies using the domestic resource costs (DRC) or revealed comparative advantages (RCA) methods to evaluate comparative advantages in aquaculture production or trade (Cai and Leung, 2007; Cai, Leung and Hishamunda, 2009), there is a lack of studies on assessing a country's or region's comparative advantages in aquaculture relative to other competing sectors. A major constraint in this line of research is the lack of appropriate data.

¹² For example, the antidumping measures used by the United States of America in the early 2000s to restrict shrimp and catfish imports were allegedly intended to protect domestic seafood producers (World Bank, 2006).

countries) used antidumping tariffs, stringent market standards or other barriers to protect inefficient domestic industries, while importing countries accused seafood exporters of gaining unfair competitive advantage through ignoring environmental and social costs and asked for leveling of the playing field. Such disputes are unfortunate; low exporting prices are actually not in the interest of exporting countries because they tend to lower their incomes from aquaculture production.¹³ Although it is not sensible or possible for fish farmers to form a cartel to limit production for higher revenues, fish farmers as well as policy-makers should understand that demand for seafood is constrained by people’s incomes and preferences, and that increasing the supply to already saturated markets would only lower prices without increasing revenues. While boom-bust cycles may be a common adjustment process under the competitive market mechanism, severe price fluctuations tend to cause hardships for fish farmers, especially small-holder fish farmers who lack bargaining power and tend to be price-takers in both input-purchasing and output-selling markets.

How to avoid flooding the market is a challenge faced by fish farmers that compete for common markets (Lovatelli *et al.*, 2008). When there is excess supply in international markets, governments tend to stabilize seafood prices by promoting domestic consumption and helping fish farmers explore other markets. While such remedies are helpful, it is equally important to provide timely information about market demand and competition conditions at all levels (i.e. global, regional, domestic, and local) to prevent market glut. Modern information technology (e.g. Internet) makes such information a valuable yet affordable public good that can benefit many stakeholders and lead to more orderly market conditions.¹⁴

Social impacts

Being socially acceptable is another objective of aquaculture development in the new millennium. While being economically viable and environmentally responsible are two basic requirements for aquaculture to be socially acceptable, the sector is expected to contribute to various social objectives, including poverty alleviation, food security, human development, and empowerment of women, among others.

Poverty alleviation

Uneven distribution of the benefits and costs of rapid aquaculture development among different groups of stakeholders would tend to cause social conflicts and disrupt the original social order. Thus, pro-poor development is a major challenge of aquaculture activities in the new millennium (World Bank, 2006).

¹³ For example, according to FAO FishStat data, the volume of Ecuador’s shrimp export was nearly 40 percent higher in 2006 than in 1996, while the value of the export was nevertheless 5 percent lower.

¹⁴ For example, there are numerous Websites in China providing all kinds of information related to aquaculture, such as technology, input prices, daily seafood retail prices, etc. (Cai and Leung, 2006).

There is ample evidence indicating that aquaculture can make a significant contribution to poverty alleviation (World Bank, 2006; De Silva and Davy, 2010). As a novel way of utilizing natural resources, aquaculture provides rural farmers alternative livelihood means (Gurung *et al.*, 2010). As a new and rapidly expanding sector with great market potential and frequent technical breakthroughs, aquaculture can provide higher incomes to rural farmers than traditional agriculture and fisheries activities (World Bank, 2006; Mente *et al.*, 2007). Integrated agriculture-aquaculture operations such as rice-fish farming allow rural farmers to increase productivity and diversify their income sources (Miao, 2010).

While economic growth lays the foundation for poverty alleviation, poor people need extra attention because there are various constraints hindering them from enjoying the benefits of economic growth. In aquaculture, poor rural farmers usually lack capital and access to credits, technical skills and management expertise, political influence and bargaining power. These constraints put them in disadvantageous situations in resource allocation and competition and hinder them from enjoying the benefits of aquaculture development (Ahmed and Lorica, 2002). Sustained public supports (e.g. tax exemption and subsidies, infrastructure construction, providing quality seed, capacity building through information exchange, training and extension, promoting technology innovations and transfer) have been a key to neutralizing such constraints and helping the poor enjoy the benefits of aquaculture development (World Bank, 2006).

For the purpose of poverty alleviation, public policies and supports often lean towards promoting small-scale aquaculture. In Asia, where small-scale farmers are the dominant force in aquaculture, there are pro-poor regulations to prevent monopolization by forbidding transfer of aquaculture licenses or permits, limiting farm size and requiring large operations to be nucleus farms that assist small-scale farmers (Hishamunda *et al.*, 2009).¹⁵ Small-scale aquaculture operations tend to be more flexible and resistant to negative shocks because the costs of terminating them in bad times and restarting in good times are relatively small as compared to those of large-scale operations (Kongkeo and Davy, 2010). However, small-scale operations have disadvantages such as lack of resources and technical know-how, being difficult to coordinate, lack of economy of scale, weak bargaining power, etc.¹⁶ While public supports and farmers' groups as well as other institutional arrangements can help small-scale farmers mitigate such shortfalls (World Bank, 2006), it remains questionable whether it is wise

¹⁵ Under the nucleus-estate model, commercial farms that wish to gain economy of scale from large operations have to agree to distributing grow-out ponds to landless farmers for their eventual ownership and providing material, technological and marketing supports to help these farmers become economically viable (Hishamunda *et al.*, 2009).

¹⁶ The compliance costs for satisfying stringent food safety standards established by developed countries are often too high for unorganized small-scale farmers, who tend to be forced out of business (FAO, 2006).

to intentionally restrain the development of large-scale operations in order to protect small-scale farmers, even from the pro-poor perspective, because large commercial enterprises can also be pro-poor by supplying leadership, knowledge and innovation (World Bank, 2006).¹⁷

Another controversial issue is the choice between low-value and high-value farming species. Farming low-value species (e.g. carp) is less demanding in technology and management and can bring food to the table. However, the profitability of farming low-value species is usually low because of limited market potential. Farming high-value species (e.g. shrimp), on the other hand, tends to be more profitable yet more difficult and risky, especially for farmers who lack financial resources, technical skills and management expertise. Thus, there are concerns that farming high-value species, notwithstanding its high profitability, may marginalize the poor. However, this may not necessarily be the case when poor farmers who are unable to take on aquaculture by themselves can still benefit from the economic impacts of aquaculture development.¹⁸

While much effort from governments and development agencies has been spent to promote subsistence, low-trophic-level aquaculture for the purpose of poverty alleviation and food security, business-oriented aquaculture has received relatively less public support.¹⁹ However, evidence indicates that farming high-value species for export may be a better alternative to realize the goal of poverty alleviation than farming low-value species for local markets or personal consumption because of the former’s large profit potential (World Bank, 2006).²⁰

Food security

Aquaculture can contribute to food security from several aspects: seafood from aquaculture provides high-quality protein and other nutrients, commercial aquaculture provides incomes and foreign exchanges that can be used to purchase food from local or international markets, and aquaculture production expansion makes seafood cheaper and more accessible to low-income people (FAO, 2006; Kawarazuka and Béné, 2010). Aquaculture’s contribution to food

¹⁷ Unlike Asia where aquaculture operations are mostly small scale, Latin America’s aquaculture is dominated by large commercial operations. Comparing the impacts on poverty alleviation of these two different industrial organizations may provide insights about this issue.

¹⁸ For example, while brackishwater aquaculture in the Philippines was relatively concentrated in the hands of rich farmers, poor households also received large benefits because development of the industry generated a large demand for unskilled labour (Irz *et al.*, 2007).

¹⁹ According to a survey of the opinions of aquaculture experts, major constraints to aquaculture development in Africa include the predominance of government or donor-driven investments promoting subsistence aquaculture and the lack of policies supporting profit-driven commercial aquaculture (Hishamunda, Poulin and Ridler, 2009). In contrast, in West Bengal, India, a shift of economic policy to export-led growth has resulted in rapid shrimp farming development in the region (World Bank, 2006).

²⁰ For example, the annual return from farming 2 000 grouper in the Philippines is equal to growing 30 000 milkfish, and the former requires only half as much investment as the latter (Hishamunda *et al.*, 2009).

security is one of the reasons why experts think that the sector should be encouraged (Hishamunda, Poulin and Ridler, 2009).²¹

However, aquaculture may have negative impacts on food security. For example, aquaculture's impacts on the local biophysical environment may negatively affect the food security of stakeholders (i.e. agricultural farmers and fishers) whose activities compete with aquaculture for natural resources (World Bank, 2006). While access to the international market allows countries to exploit their comparative advantages and gain from trade, there are concerns that export-oriented policies may divert resources away from other important domestic food sources such as small fisheries (FAO, 2006). Moreover, overly specializing in a couple of export species would put the country in danger of economic disasters from price fluctuations, disease outbreaks, natural disasters, etc.²²

Another concern is that profit-driven aquaculture production may not utilize natural resources in the best way for food security. One well-publicized issue is that the farming high-valued species (mostly carnivorous marine species) may be an economically profitable but biologically wasteful process that uses more biomass to produce less (Naylor *et al.*, 2000). Using fish suitable for direct human consumption to produce feed materials for aquaculture may drive up the prices of low-value fish and hence negatively affect the food security of low-income households (Tacon and Metian, 2009). Although small fish are generally more nutritious and affordable (Kawarazuka and Béné, 2011), aquaculture nevertheless prefers to culture bigger species that are more economically profitable (Ahmed and Lorica, 2002). While farming high-value or bigger species may not be an efficient way of supplying nutrient from a biological perspective, it is not necessarily bad for food security because incomes and foreign exchange from selling cultured seafood can be used to purchase food from domestic or international markets (Hasan and Halwart, 2009). Indeed, a large portion of seafood products are traded across borders, with developing countries being main exporters and developed countries being main importers; undernourished countries produce high-value seafood for export and import low-value fish for their own consumption (Smith *et al.*, 2010). However, in the long run, relying on low-trophic-level fish as inputs to produce high-trophic-level species may not be sustainable (Tacon *et al.*, 2010).

The impacts of increasing commercialization and globalization of aquaculture production on food security are complex and not well understood. While the

²¹ Aquaculture accounted for 47 percent of fish available for per capita world human consumption in 2006, increasing from 30 percent in 1996 and 14 percent in 1986 (FAO, 2009). Aquaculture provides 22 percent of protein intake in sub-Saharan Africa, where hunger has been a major problem (FAO, 2006).

²² For example, Ecuador's shrimp farming industry lost about half a million jobs in 2000 because of white spot syndrome virus (WSSV); and consequently the Government of Ecuador had to declare a state of emergency to help workers and growers who suffered from income and employment losses (FAO, 2006).

declining prices of high-valued seafood (e.g. shrimp and salmon) in the new millennium have made them more accessible to common people (FAO, 2006), the prices of low-valued captured fish are nevertheless driven up by increasing demand for aquaculture feed (Smith *et al.*, 2010), which would benefit rural farmers who are net food producers but harm those who are net food consumers (Godfray *et al.* 2010). However, evidence indicates that the prices of low-value cultured fish (e.g. carp) have declined because of aquaculture development (FAO, 2006). The need for research to identify the impact of increasing commercialization and globalization of aquaculture on food security is a key issue.

Human development

There were around 8.7 million people directly engaged in fish farming in 2006 globally (FAO, 2009), and the number is expected to be much higher when people engaged in aquaculture-related businesses (e.g. seafood processing) is taken into account (FAO, 2006).²³ There is evidence indicating that aquaculture workers can earn higher wages (e.g. from catfish farming in Viet Nam) than workers involved in other agricultural activities (World Bank, 2006), while there are also reports indicating that aquaculture workers (e.g. in the salmon industry of Chile) were subject to hardships such as low wages, long working hours, and no union rights (Allsopp, Johnston and Santillo, 2008).

In addition to providing incomes and jobs, aquaculture contributes to human development through improving human health. As a food producer, aquaculture contributes to human health by providing high-quality protein and other nutrients (e.g. minerals, vitamins, fatty acids). Active human interventions in the production process allow aquaculture to improve the nutritional value and taste of aquatic products (Hasan, 2001). Aquaculture can also alleviate food safety problems (e.g. chemical and metal contamination, infectious diseases, parasites) by raising fish in controlled environments (Howgate *et al.*, 1997). However, there is a general perception that cultured products tend to be less nutritious, healthy and tasty than wild seafood. While this may be an outdated and misinformed opinion, it nevertheless reflects the fact that poor farming environment, low-quality feed ingredients, and imprudent use of chemicals in farming and processing methods can negatively affect the quality of aquaculture products (FAO/NACA/WHO, 1999; FAO, 2006), which in turn, would tend to negatively affect human health (GESAMP, 1991). Under the pressure of more stringent food safety regulations and more demanding consumer demands, the quality of cultured products has been improved and is expected to continue improving.

In addition to providing healthy food, aquaculture can also have positive impacts on human health by controlling human disease vectors (e.g. mosquitoes and snails). However, abandoned or poorly managed aquaculture ponds may

²³ Employment data in aquaculture are rarely available; the number of jobs provided by aquaculture is sometimes estimated from other data such as production figures (Hishamunda *et al.*, 2009).

cause water-borne diseases (Brugere, 2006). Aquaculture operations are also associated with occupational hazards such as animal bites, stings from fish spines, slips, trips, falls from heights, machinery accidents, excessive noise exposure, chemical or biological exposure, confined working spaces, etc. (Erondu and Anyanwu, 2005; Moreau and Neis, 2009).

Aquaculture can not only make people healthier but can also help them to become smarter. As aquaculture becomes increasingly sophisticated and knowledge intensive, fish farmers' knowledge and skills have improved accordingly (World Bank, 2006). While training and extension provided by governments or private companies are a major contributing factor to such human capital accumulation, the opportunity to take part in a vibrant and competitive industry is the most effective training ground for capacity building.

Empowerment of women

Many aquaculture operations (e.g. seed collection, postharvest processing and trading) are suitable for women's participation. However, negative social attitudes as well as other obstacles (e.g. lack of land) tend to hinder women from taking such opportunities (Ahmed and Lorica, 2002). Experiences of countries with women's involvement in aquaculture differ. While there are many women in the aquaculture work force (especially as hired labour in processing plants) in Bangladesh, Thailand and Viet Nam, women's participation in aquaculture is low in Malaysia and Myanmar (Karim *et al.*, 2006; Hishamunda *et al.*, 2009). While women's involvement in aquaculture is insignificant in the Near East and North Africa, they play a dominant role in fish processing and trading in western and some southern African countries (FAO, 2006). While such discrepancies may reflect different cultural, ethnic or religious traditions, further research on factors affecting women's roles in aquaculture is needed to facilitate better understanding of aquaculture's contribution to the empowerment of women. In general, while there is still gender imbalance in aquaculture employment (FAO, 2006), opportunities provided by aquaculture have contributed to empowering women and improving their status and well-being (Brugere and Kusakabe, 2001; Brugere, McAndrew and Bulcock, 2001).

Community cohesion and social order

While rural youth in developing countries often go to urban areas for higher paid jobs and more opportunities, business and employment opportunities brought by aquaculture development can check such a tendency and retain important human resources for rural development (NACA, 1994). Rapid aquaculture development may actually attract immigration of labour to local communities, which would nevertheless put pressure on the original social order and cause social conflicts (Rijsberman, 1999; Lewins 2006).

As discussed above, while incomes, jobs, infrastructure and other economic contributions of aquaculture tend to have positive impacts on rural development,

aquaculture’s competition and negative environmental externalities have caused conflicts between fish farmers and other stakeholders and disrupted social order. Experiences in many countries indicate that when profit-driven aquaculture results in a large amount of resources flowing into the production of a highly profitable single crop (e.g. shrimp), some local people are able to grab the opportunity and become better off, while others are marginalized because of various constraints; and worse still, their requirements for livelihood and environment were often neglected (Barraclough and Finger-Stich, 1996). The resulting increase in inequality tends to cause social conflicts.

When export-led commercial aquaculture opens rural communities to the outside world, the traditional values and way of life would tend to be impacted. People may become more open, ambitious and competitive and pay increasing attention to financial success. Traditional customs and the cultural heritages of indigenous people may be suppressed by profit-seeking aquaculture activities. As a highly profitable and regulated business, aquaculture development may foster rent-seeking behaviours.²⁴ While such impacts have complicated and significant implications for stakeholders’ social well-being, research in this area is generally lacking.

Institutional arrangements and sustainable aquaculture development

While an environmentally responsible, economically viable and socially acceptable aquaculture sector is an outcome perhaps desirable for everyone in the long run, it is nevertheless difficult to achieve because of coordination failures caused by unclear or unprotected property rights, externalities, imperfect information, high transaction costs and other constraints. Public interventions are often applied to neutralize or mitigate such constraints, which nevertheless may not be effective and sometimes can be counterproductive. Thus, appropriate institutional arrangements are needed to align various stakeholders’ interests, encourage cooperative behaviour and facilitate win-win solutions.

Aquaculture development in the new millennium has witnessed an increasing trend of command and control measures being replaced by economic incentives and more management responsibilities being transferred from public administration to the private sector. Co-management through partnership among various stakeholders (e.g. governments, aquaculturists, researchers, civil societies) has been promoted to create a democratic and transparent decision-making process for more realistic, implementable and effective policies. Public policies and programmes, quality standards and certification schemes, as well as voluntary codes of conduct and self-regulatory practices have been adopted

²⁴ For example, public tilapia hatcheries in the Philippines are sometimes viewed as a source of corruption (Hishamunda *et al.*, 2009).

or encouraged to move the sector towards the goal of being economically viable, environmentally responsible and socially acceptable.

Despite the progress made, institutional arrangements for aquaculture development have not been well developed in some countries. Problems include lack of specific legal framework, lack of well-defined policy goals, lack of specific strategies to implement policies, ineffective policies because of poor awareness or shortage of human capacity for implementation, etc. (FAO, 2006).

In the remainder of this section the role of institutional arrangements in facilitating sustainable aquaculture development is reviewed and the underlying causes of environmental, economic and social constraints on sustainable aquaculture development are analyzed; existing and potential institutional arrangements for neutralizing or mitigating these constraints are discussed; and the tradeoffs among aquaculture's environmental responsibility, economic viability and social acceptability are highlighted.

Institutional arrangements for environmentally responsible aquaculture

There are several obstacles hindering aquaculture from being environmentally responsible. These include knowledge constraints (fish farmers may not be aware of the negative environmental impacts of their operations or not know how to avoid or mitigate such impacts), externalities (fish farmers do not need to pay for the negative environmental impacts of their operations on others), and coordination failures (fish farmers are not willing to individually internalize their externalities because of the pressure of competition), among others. Various institutional arrangements can be applied to discourage environmentally degrading activities through legal or regulatory forces or to encourage environmentally responsible behaviours through market forces or by facilitating coordination and cooperation.

Laws and regulations

Laws and regulations are the most common measures to address the resource and environmental problems of aquaculture development. With increasing concerns about environmental protection, countries worldwide have become more active in regulating nearly every aspect of aquaculture operations (e.g. site selection, farm size, use of water, feed, chemicals, and wild species, disease control, escapee control); environmentally degrading aquaculture activities are either highly restricted or completely prohibited. However, since aquaculture is still a relatively small and not yet fully established sector, most countries lack a comprehensive regulatory framework specifically for the sector. There are usually no independent aquaculture laws but only aquaculture-related chapters or clauses under more general fisheries laws, and environmental regulations applicable to aquaculture are usually established and implemented by diverse agencies with little consideration or coordination in accounting for

aquaculture’s specific situations (FAO, 2007b; Hishamunda *et al.*, 2009).²⁵ In addition, difficulties in monitoring and enforcement tend to make environmental regulations over aquaculture ineffective.²⁶

Notwithstanding being arbitrary and inflexible, laws and regulations are essential institutional arrangements for making aquaculture environmentally responsible because they establish clear guidelines to enforce sustainable behaviours by the sector. However, enforcement of laws and regulations tends to be costly, and their effectiveness requires good governance that is usually lacking in developing countries. In addition, inappropriate or cumbersome laws and regulations tend to inflict undue costs upon and hence constrain aquaculture development. Countries’ experiences indicate that effective and efficient aquaculture laws and regulations require the active involvement of the private sector (FAO, 2007b).

Evidence indicates that government regulations tend to be more stringent in countries that have already paid high environmental costs for aquaculture development (e.g. Thailand and the Philippines) than in newcomers, such as Myanmar and Viet Nam (Hishamunda *et al.*, 2009), which indicates that government regulations tend to be reactive for mitigating existing environmental problems rather than proactive for preventing potential problems. This is understandable because government usually puts more emphasis on economic growth (as a benefit) than on environmental protection (as a cost), and the biophysical environment may be too complex for anyone to practically know in advance when nature’s carrying capacity would be reached.²⁷ However, considering the tremendous costs of environmental degradation to society as well as to the industry *per se*, further research on how government policies can strike a proper balance between economic growth and protection of the environment is warranted.

Environmental impact assessment

Environmental impact assessment (EIA) has been increasingly used to avoid or reduce aquaculture’s negative impacts on the environment. Many countries in Latin America now require mandatory EIA as a precondition for granting

²⁵ For example, “the regulatory structure for aquaculture often does not allow or facilitate a production mode or approach that is conducive to a balanced ecosystem. Nutrient cycling and reutilization of wastes by other forms of aquaculture (polyculture) or local fisheries are frequently prohibited or discouraged” (FAO, 2007b, p. 78). See Agüero, Hishamunda and Valderrama (2009) for a detailed review of aquaculture laws and regulations in Latin America, and Hishamunda *et al.* (2009) for the situation in Asia.

²⁶ For example, prohibitions of using mangroves for aquaculture in the Philippines and Viet Nam had little impact because of lack of resources and human capacities to enforce the regulations (Agüero, Hishamunda and Valderrama, 2009).

²⁷ For example, in spite of past disease outbreak experiences of salmon farming in Norway and shrimp farming in Latin America and Southeast Asia, Chile’s salmon farming industry did not avoid being the victim of a recent disease outbreak that wiped out nearly half of the industry’s production (Barrionuevo, 2008; Arengo *et al.*, 2010).

aquaculture licenses or permits. However, EIAs are usually not required for existing aquaculture operations and hence do not provide detailed information about mitigating measures for addressing existing environmental problems (FAO, 2007b).

The applicability of EIA to small-scale operations tends to be limited because it usually evaluates the environmental impacts of individual operations independently without considering their potential aggregate impacts (FAO, 2007b). Also, the compliance costs for EIA tend to be burdensome for small-scale operations. Thus, in Asia, EIA is usually required only for large operations (Hishamunda *et al.*, 2009).²⁸

Environmental taxes

Based on the “polluter pays” principle, environmental taxes can be used to internalize individuals’ negative environmental externalities and hence discourage environmentally degrading behaviours. While the idea is theoretically sound, this method faces practical problems in aquaculture, such as difficulties in determining appropriate tax rates and in monitoring environmentally degrading activities or assessing negative environmental impacts. Thus, environmental tax is rarely applied in aquaculture.²⁹

Ecolabelling

Ecolabelling is, in essence, a scheme that uses market force to encourage environmentally responsible behaviours, under which goods produced with environmentally friendly practices are trademarked (usually through third-party certification) and catered to consumers who are concerned about environment protection. Ecolabelling has become increasingly popular in aquaculture and is used widely in developed countries’ marketplace (Ababouch, 2007; Siggs, 2007; Ward and Phillips, 2008).

While theoretically ecolabelling tends to encourage environmentally friendly behaviours in aquaculture, practical issues may render the scheme ineffective or even counterproductive. Firstly, certification costs, if higher than the extra profit (price premiums less compliance costs) brought by ecolabelling, would not only be ineffective in inducing environmentally friendly behaviour but would also tend to discourage fish farmers who would adopt environmentally friendly operations even without ecolabelling. Secondly, ecolabelling may deviate from its original mandate of environmental protection and become a marketing strategy (e.g. retailers may use ecolabelling or other market standards to gain market power) (Ababouch, 2007). Thirdly, without proper regulation, the coexistence of an increasing number of ecolabelling and other certification schemes sponsored

²⁸ For example, in Indonesia, EIAs are “required for farms of at least 50 ha in brackishwater zones, and for larger farms in lakes and in marine waters.” (Hishamunda *et al.*, 2009).

²⁹ There is no report of environmental taxes being used in aquaculture in a series of regional reviews of aquaculture status in 2006 (FAO, 2006).

by governments, advocacy groups or private companies would tend to confuse consumers and reduce the effectiveness of ecolabelling as a whole (Ababouch, 2007). Fourthly, complicated and costly application and compliance procedures would make ecolabelling discriminate against small-scale farmers (Phillips, Ward and Chaffee, 2007).

While ecolabelling may be a better scheme to express consumers’ environmental concerns than boycotts or consumer choice guides, the environmental as well as economic impacts of ecolabelling or other certification schemes in aquaculture are yet to be fully understood (Roheim, 2009). Further study in this area is warranted.

Self-regulation

Institutional arrangements discussed above use either legal-regulatory or market-driven incentives to discourage environmentally degrading behaviours or motivate environmentally responsible behaviours. These mechanisms tend to be costly and may not be effective because of poor governance. When applied to a large number of small-scale farmers, such schemes tend to be even more costly and less effective. Thus, self-regulation has been promoted as a complementary approach to protect the environment (FAO, 2006). To be effective, self-regulation needs clear guidelines for environmentally responsible practices and coordination mechanisms to facilitate them. Technical and financial supports may also be needed to make these practices economically viable.

Codes of conduct (or technical guidelines) have been established by governments, international agencies or private companies to increase the awareness of and provide clear guidelines for environmentally responsible aquaculture operations; the most well-known is the *FAO Code of Conduct for Responsible Fisheries* (FAO, 1995). There are a number of aquaculture-related codes of conduct or technical guidelines at the international level (sponsored by international agencies such as FAO, the International Council for the Exploration of the Sea (ICES) and the Network of Aquaculture Centres in Asia-Pacific (NACA)), the national level (sponsored by individual governments) and the industry level (sponsored by producers associations or large private companies).³⁰ While much effort has been spent in promoting these codes of conduct, fulfillment of these voluntary codes is difficult to monitor or verify, especially for a large number of small-scale farmers (FAO, 2006).

Farmers associations have been playing an important role in promoting environmentally responsible aquaculture practices among small-scale fish farmers (FAO, 2006). Peer pressure and role models sometimes can be more effective in inducing responsible behaviour than legal-regulatory or market

³⁰ See World Bank (2006, Annex 2) for a list of aquaculture-related codes of conduct and technical guidelines.

forces because their impacts tend to be more direct, timely and straightforward. Coordination under farmers associations can also facilitate training and extension, information, experience and risk sharing, access to financial resources and public supports and increase farmers' bargaining power. Countries' experiences indicate that being organized is one key factor for successful adoption of best management practices (BMPs) among small-scale fish farmers (FAO, 2006).

Best/better management practices (BMPs) are a means to sustain environmentally responsible aquaculture behaviours being voluntarily adopted by small-scale farmers. Countries' experiences indicate that BMPs, when taken by most farmers in a coordinated manner will not only reduce negative environmental impacts but can also increase fish farmers' profitability by raising productivity and reducing the costs of disease prevention and outbreaks (FAO, 2006).³¹

Institutional arrangements for economically viable aquaculture

Aquaculture development in the new millennium has been driven by free market access and facilitated by technological innovations. While population growth, economic growth and increasing consumers' preference for healthy food are expected to sustain strong seafood demand in the future, aquaculture faces constraints such as a lack of suitable sites, shortage of seed and feed, high energy prices and lack of infrastructure, among others (FAO, 2009). While environmental protection requires that fish farmers' behaviours be restricted, facilitating the economic viability of aquaculture requires that constraints be removed to facilitate the proper functioning of the market mechanism.

Trade barriers

Tariffs

Tariffs over seafood imports in developed countries (as the main seafood import markets) are generally low (FAO, 2009), but there are still "tariff peaks" and "tariff escalation" on value-added products from developing countries, which tend to constrain the development of the seafood processing industry in developing countries (Li, 2007). Also, tariffs for seafood imports in developing countries are relatively high, which tends to restrict free trade among developing countries (World Bank, 2006). Nevertheless, under the general trend of globalization and free trade, tariffs are not expected to become a major trade barrier for aquaculture products in the future.

³¹ For example, adoption of better management practices for shrimp farming under shrimp health management projects in India has led to "reduction in disease prevalence by 65 percent, two-fold increase in production, 34 percent increase in size and improvement in quality of shrimps due to non-use of banned chemicals"; and in Viet Nam, the results were "1.5 times higher seed production by better managed hatcheries with 30 to 40 percent higher selling price for the fry, higher production and higher probability of making a profit, improved yields that were up to four times higher than non-BMP ponds." (FAO, 2006, p.107).

Antidumping

Antidumping is a trade barrier often used by developed countries against cheap imports. Antidumping measures were used by European countries and the United States of America to restrict salmon imports in the 1990s (Asche, 1997), and by the United States of America to restrict shrimp and catfish imports in the 2000s (World Bank, 2006; GLOBEFISH Highlights, 2009). Although antidumping charges are sometimes motivated by protectionism, they are legitimate measures under the rules of the World Trade Organization (WTO). Thus, the best way to deal with them is to be well prepared for dumping investigations with clear documentation of non-dumping evidence. As the costs of defending antidumping charges tend to be too high for individual farmers (especially small-scale farmers), governments or producers associations are usually needed to facilitate coordinated actions against antidumping charges (Cai and Leung, 2006). As the countervailing tariffs tend to be prohibitive for exporters found guilty of antidumping and seriously disrupt the industry, governments may consider adopting voluntary export restraining measures to avoid being subject to antidumping disputes.³²

Market standards

Market standards are another major barrier in the international seafood trade. Lack of ability to adhere to food safety and quality requirements is a major barrier for developing countries to access developed countries’ import markets (FAO, 2009). Public food safety standards for seafood imports to developed countries are usually stringent, and their violation tends to be very costly.³³ In addition, large retail and restaurant chains with dominating market power would also like to impose private environmental and social standards (concerning animal welfare, child labour, human rights, etc.) on their procurements, the compliance costs of which are often cumbersome or prohibitive for small-scale (or even large yet unorganized) farmers who lack capital and economy of scale (FAO, 2006). Transparency, information sharing (e.g. through e-commerce), and common customs procedures and operations among trading partners have been suggested as means to reduce compliance costs (FAO, 2006).

The rampant emergence of various private product standards and market requirements has led to several controversial issues.³⁴ One concern is that private market standards may become anticompetitive trade barriers used by

³² For example, to avoid being subject to serious trade barriers against its salmon exports, the Norwegian Government used feed quota and restriction of issuing new licenses to restrain expansion of the domestic salmon industry (Asche, 1997).

³³ For example, after detection of chloramphenicol residuals, shrimp exports to the European Union (EU) market from China were banned for two years in the early 2000s (Cai and Leung, 2006). After the detection of nitrofurans in some of its shrimp exports to the EU in 2009, the Government of Bangladesh voluntarily halted its shrimp exports to the EU for six months as a precautionary measure against potentially more severe sanctions (GLOBEFISH Highlights, 2010).

³⁴ It was estimated that there were around 400 seafood-related certification schemes; and the number is rising (FAO, 2009).

companies with significant market power to impose lower prices throughout the supply chain (FAO, 2007b). Market standards initiated by private companies are often viewed by producers and exporting countries as unjustified (i.e. being inconsistent with public standards), unnecessary (i.e. being duplications of standards competently imposed by exporting countries),³⁵ unfair (i.e. being inconsistently and discriminatorily applied to different suppliers) and uneconomical (i.e. required third-party certification being expensive with little value added). But proponents claim that private standards are useful because public standards tend to be insufficient and incompetently implemented. While market standards initiated by governments can be challenged in the WTO, there are no proper authorities to regulate private standards. In addition, the roles of and boundaries between public and private standards are generally undefined (FAO, 2009).

Regarding the confusing state of market standards in seafood trade,³⁶ further research is needed to examine the impacts of market standards on both importing and exporting countries and to assess the costs and benefits of their implementation and compliance and the impacts on various stakeholders (FAO, 2007b).

Public interventions in aquaculture production

Property rights

Property rights are established in aquaculture through leases, licenses, permits, concessions or authorizations. The tenures of aquaculture leases are usually long (more than 10 years) and renewable or sometimes indefinite (e.g. in Chile), which is good for fostering long-term behaviours. There are usually user fees associated with aquaculture leases, which sometimes are not large enough to reflect the opportunity costs of land being used (e.g. in the Philippines) and hence provide no incentives for intensification. There are usually restrictions (e.g. over farm size, ownership transfer, foreign ownership) or requirements (e.g. EIA, environmental licenses, project plans) associated with aquaculture leases for the purpose of preventing monopolization or protecting the environment. While such restrictions tend to impose constraints on fish farmers' operations, there seems to be ways to circumvent them.³⁷ The bureaucratic processes of

³⁵ While countries with a developed aquaculture sector (e.g. Thailand) may have well-established objectives and institutions to enforce food safety standards, newcomers (e.g. Myanmar) tend to be underdeveloped in this respect (Hishamunda *et al.*, 2009).

³⁶ Studies found that shortcomings of existing market standards in seafood trade include "limited openness in governance of standards and insufficient multi-stakeholder participation in their development; few meaningful, measurable and verifiable criteria addressing the key areas of concern; insufficient independence in the operations of the bodies responsible for creating, holding, inspecting and certifying standards; frequent absence of effective mechanisms for applying corrective measures and sanction procedures as well as a deficient certification of the chain of custody." (FAO, 2009, p. 100).

³⁷ For example, fish farmers in the Philippines have relatives apply for adjacent lands in order to neutralize the land size restriction and gain economy of scale, and foreign investors sometimes use local people as "fronts" to bypass the regulation that at least 60 percent of the farm ownership must belong to Philippine nationals (Hishamunda *et al.*, 2009).

granting aquaculture permits, which used to be time consuming and inefficient, have been greatly improved in most countries (Hishamunda *et al.*, 2009).

The case of Myanmar is unique and worth noting. As a newcomer in aquaculture, the country sets no restrictions over area and size for aquaculture but allows only short periods (up to three years) for aquaculture operations other than pond culture (Hishamunda *et al.*, 2009). The freedom over area and size is attractive to large-scale farming investors because it allows them to have economies of scale, but the short period of tenure (albeit with possibility of renewal) and other restrictions and requirements associated with the lease (e.g. water surface area must occupy no less than three quarters of the leased land; the farm must be operational in three years and fully operational in five years) may foster short-term behaviours. It remains to be seen whether such a unique institutional arrangement can help the country achieve rapid aquaculture development in the short run without long-term problems.

Seed production

Seed production is a crucial stage of aquaculture operations; breakthroughs in aquaculture were often triggered by availability of abundant and high-quality seed. Asian countries’ experiences indicate that proper public-private partnership is an important factor for facilitating seed industry development in aquaculture (Hishamunda *et al.*, 2009). In Asia, public hatcheries were initially established to supply fry and fingerlings and demonstrate hatchery technologies, and when private hatcheries became developed, public hatcheries were usually either privatized or focused on species underprovided by the private sector. However, as non-profit organizations, public hatcheries may disrupt the seed market by supplying low-priced or poor-quality seed; and they sometimes are associated with corruption. Public support for development of private hatcheries (e.g. tax exemptions, subsidies, access to credits, technical assistance, providing high-quality bloodstocks, organizing seed markets) have proven to be a better alternative for the development of the seed industry in aquaculture. For the purposes of maintaining seed supply and quality and preventing diseases, seed production and trade have been under stricter public regulations (e.g. licensing, certification, International Organization for Standards (ISO) standards), which sometimes have negative impacts on seed producers’ profitability.³⁸

Feed production

Feed production is a lucrative business in aquaculture because feed costs usually account for a major part of production costs (especially in intensive aquaculture operations). In Asia, the importance of feed supply in aquaculture operations and the shortage of feed ingredients have led to increasing public supports to the industry (Hishamunda *et al.*, 2009), while in Latin America,

³⁸ For example, the Philippines’ ban of exporting milkfish and shrimp seed deprived hatchery operators of the opportunities to take advantage of seasonal demands from abroad (Hishamunda *et al.*, 2009).

where feed ingredients are abundant, aquaculture feed production is dictated mainly by market forces, with public regulation of permissible feed ingredients for environmental protection or food safety purposes.³⁹ Shortage of aquaculture feed ingredients (fishmeal and fish oil) and consequential increases in their prices have become a major and increasing challenge to sustainable aquaculture development,⁴⁰ especially in regions that heavily rely on imported fishmeal and fish oil (e.g. Asia). In the short run, tariff reductions or exemptions on imported feed or feed ingredients have been applied to help mitigate the negative impacts of rising feed prices on fish farmers (Hishamunda *et al.*, 2009), while in the long run, proactive public support is called for to help find other cost-effective feed ingredients and to increase the productivity of feed production through promoting large-scale feed mills and encouraging foreign investments (Hishamunda, Poulin and Ridler, 2009).⁴¹

Financial capital

Financial capital has been a major bottleneck for aquaculture development.⁴² The risky nature of aquaculture and incomplete understanding of the business by investors, creditors and insurance companies are two major factors deterring investments in aquaculture. While credits from feed or seed producers are sometimes available to finance fish farmers' daily operations, start-up funds for infrastructure construction and other capital investments are more difficult to obtain, especially for small-scale farmers who lack the resources and skills needed to satisfy banks' collateral and documentation requirements. Various public supports (e.g. encouraging banks to lend to small farms, providing financial supports to farmers' cooperatives, public-initiated loan programmes, interest rate subsidies, tax breaks) have been applied in Asia to help small-scale farmers access credits and reduce their financial burdens. Experience indicates that government agencies usually lack expertise and incentives to allocate public funds effectively and efficiently; public credit programmes tend to benefit large borrowers instead of helping the poor, and repayment performances are usually poor (Hishamunda *et al.*, 2009).

Foreign direct investments

Foreign direct investments (FDI) are a popular way for underdeveloped sectors to overcome financial constraints because foreign investors tend to bring not

³⁹ For example, only residuals from food processing or species not suitable for direct human consumption are allowed to be used to produce aquaculture feed in Ecuador; fresh crustaceans (except *Artemia*) are not allowed to be used in feed production in Mexico; and use of animal meat is not allowed in aquaculture feed production in Chile (Agüero, Hishamunda and Valderrama, 2009).

⁴⁰ The prices of fishmeal and fish oil increased dramatically in the mid 2000s because of reduced supply and buoyant demand from China. While the prices stabilized afterwards, they have been rising strongly since 2009 (GLOBEFISH Highlights, 2010).

⁴¹ For example, leftovers from fish processing (e.g. canned tuna and surimi) has been used as ingredients in Thailand to produce fishmeal that has better quality than trash fish from capture.

⁴² In a recent survey, experts in all regions except Eastern Europe deemed lack of capital a major challenge to aquaculture development in their respective regions (Hishamunda, Poulin and Ridler, 2009).

only capital but also other side benefits (e.g. technical know-how, management expertise, market access). While there are favourable policies (e.g. tax and tariff exemptions, guarantee of repatriation of profits) to encourage foreign investments in aquaculture, there are also restricting policies (e.g. upper limit of foreign ownership in aquaculture operations) intended to prevent them from being dominant. For countries (e.g. in sub-Saharan Africa) that possess abundant natural resources but lack human and financial resources as well as the proper institutions to realize their potentials in aquaculture, foreign investments have a great potential to provide the first push that helps the sector overcome various constraints and start in the growing track. Further research on how foreign investments may help aquaculture development in Africa is warranted.

Technology and know-how

Technology and know-how tend to be underprovided in the aquaculture sector because farmers usually lack resources and incentives to undertake aquaculture research that would benefit the entire sector. While protection of intellectual property rights (IPRs) (through patents, trademarks, copyrights, etc.) can motivate technological innovations in aquaculture (Ninan *et al.*, 2005), there have been controversies over the extent of private IPRs (e.g. whether genetically modified organisms (GMOs) are allowed to be patented), and the social benefits and costs of private IPRs in aquaculture are generally unclear (Dunham *et al.*, 2001; Beardmore and Porter, 2003).

Public supports are often needed to facilitate technology advancement in aquaculture. However, to be relevant, public-funded research needs to be guided by industry needs. Thus, proper public-private partnership is crucial for fruitful technological advances in aquaculture. In Asia, there are usually specific government agencies responsible for research and technological development in aquaculture; and fish stations, one-stop aqua shops (OAS) or other kinds of service centers were established to provide seed and other materials, training and extension, technical assistance, information about prices and policies, etc. International agencies, non-governmental organizations (NGOs) and farmers associations have also initiated many programmes for capacity building and technology transfers in aquaculture (World Bank, 2006; Hishamunda *et al.*, 2009).⁴³ However, lack of capacity in government personnel to conduct extension services and in recipients to assimilate technical assistance are still major obstacles preventing technological advances in aquaculture from benefiting more fish farmers.

⁴³ Examples include the genetically improved farmed tilapia (GIFT) financed by the Asian Development Bank (ADB), the International Network on Genetics in Aquaculture (INGA) developed by the WorldFish Center, the STREAM (Support to Regional Aquatic Resources Management) Initiatives sponsored by NACA, and the Consortium on Shrimp Aquaculture and the Environment sponsored by multiple agencies including FAO, NACA, the World Bank, the World Wide Fund for Nature (WWF) and the United Nations Environment Programme (UNEP) (World Bank, 2006).

In some regions such as Latin America, there are few technical programmes available for training mid-level aquaculture employees (e.g. farm coordinators, laboratory assistants, specialized processing plant staff), and participation in sporadically offered extension courses is often not merit-based but decided based on political, family or other connections.

Experience in Asian countries indicates that corporate approaches (e.g. contract farming and the nucleus-estate model) tend to be effective ways for technical transfer (World Bank, 2006).⁴⁴ Foreign direct investments also tend to promote capacity building and technical transfers, but their impacts in this respect are less well documented.

Institutional arrangements for socially acceptable aquaculture

In addition to environmental responsibility and economic viability, a socially acceptable aquaculture sector also entails the benefits and costs of aquaculture development being equitably distributed among various stakeholders. As many constraints hinder less-advantaged groups from enjoying the benefits of aquaculture development, pro-poor aquaculture entails significant institutional supports from governments, international agencies, NGOs, farmers associations and other organizations that promote pro-poor aquaculture.

Public policies

As discussed above, in most aquaculture countries there are public policies and regulations established to protect the interests of less advantaged stakeholders in aquaculture development. However, well-intended public policies do not necessarily achieve desirable effects.

In a recent survey, the absence of appropriate policies for aquaculture development was identified by experts as the most important factor hindering aquaculture development in Africa. According to the experts, aquaculture development policies in Africa have overemphasized promotion of small-scale aquaculture as a rural livelihood means but overlooked the potentials of commercial aquaculture in promoting economic growth, which resulted in an underdeveloped aquaculture sector predominated by government or donor-driven investments as opposed to commercially oriented private ventures (Hishamunda, Poulin and Ridler, 2009). Similarly, the experience of Latin American countries indicates that private initiatives backed up by significant institutional supports tend to facilitate aquaculture development, while over intervention (“duplication of effort”) and overregulation (“excess of rules and powers”) by authorities would hamper the progress (FAO, 2006). Asian countries’ experiences also indicate that commercial aquaculture (the “transition pathway” and the “consolidation pathway”) tends to be more effective in poverty alleviation than subsistence aquaculture (the “static model”) (World Bank, 2006, p. 44).

⁴⁴ See footnote 16 for information about the nucleus-estate model.

An important message conveyed by these experiences is that pro-poor public policies should focus on enabling the poor to participate in aquaculture business instead of attempting to shield them against competition. Thus, restrictive public policies and regulations (e.g. limiting farm size) intended to protect less-advantaged farmers should be applied cautiously, and their impacts should be monitored and assessed comprehensively. Instead of directly subsidizing aquaculture activities deemed pro-poor, governments and international agencies should focus on creating an enabling business environment through infrastructure construction, capacity building, technology innovations and other public goods that tend to be underprovided by the private sector.

Non-governmental Organizations

NGOs that commit to be guardians of the poor have contributed greatly to pro-poor aquaculture by providing training and extension services, facilitating research and technological innovations, developing standards and codes of conduct, organizing farmers, promoting BMPs, participating in public policy decision-making, monitoring public programmes and private businesses, educating consumers and increasing public awareness of development issues in aquaculture (Bostick, 2008).

As non-profit and mission-driven organizations, NGOs can be less bureaucratic than government agencies but more dedicated, flexible and efficient in pursuing their social objectives and representing their constituencies. However, lack of clear principal-agent relationships between NGOs and their constituencies may result in inconsistent advocacies. For example, some NGOs endorse the notion that farming high-value carnivorous species should be discouraged because of its bio-inefficiency (e.g. Allsopp, Johnston and Santillo, 2008), but they sometimes do not pay enough attention to the fact that farming high-value species with great market potentials can be more effective in leading poor farmers out of the poverty trap, even though pro-poor is one of their objectives.

Aquaculture’s socio-economic impacts are complex and involve many tradeoffs, but advocacy groups that dislike ambivalence sometimes choose to focus on the negative side of aquaculture. While such approaches are effective in drawing public attention to specific issues, they are nevertheless insufficient for policy recommendations that require more balanced assessment of the tradeoffs of aquaculture’s complex socio-economic impacts. In addition, unbalanced focus on aquaculture’s negative impacts would tend to antagonize the industry and take a toll on its public image.⁴⁵

⁴⁵ According to a recent survey, aquaculture experts in all regions but Eastern Europe identified the negative public images of and public opposition to aquaculture as major challenges to aquaculture development (Hishamunda, Poulin and Ridler, 2009). Commercial aquaculture is sometimes perceived as a profit-seeking, environment-degrading, drug-using and animal-abusing business that serves the appetite of the rich for food and money. While such unpleasant public images reflect the fact that imprudent or irresponsible aquaculture development would tend to cause negative socio-economic impacts, they mainly represent widespread public misperception and mistrust of the industry, which has been fostered or exacerbated by sensationalist media coverage of aquaculture.

NGOs have become increasingly influential in the aquaculture sector through certification programmes (e.g. ecolabelling) and other schemes that gather the attention and supports of consumers and hence allow them to use market forces to influence private businesses.⁴⁶ More power should be associated with more responsibility. Further research on the role of NGOs in aquaculture is warranted.

Community-based aquaculture

Being organized can help farmers gain access to markets, credits and technologies; share experiences, information and risks; enforce codes of conduct; promote BMPs; increase bargaining power; and enhance community cohesion, among others. While there are examples that community or cluster-based aquaculture can be an effective way to empower less advantaged stakeholders (Umesh *et al.*, 2010), the success of such institutional arrangements requires a cooperation mindset, organizational capacity and coordination mechanisms that rural farmers may be lacking (Radheyshyam, 2001; De and Saha, 2005).⁴⁷

While community-based aquaculture has mainly been a tool used by donors and NGOs to promote pro-poor aquaculture (World Bank, 2006), it has potential to become a self-sustained institutional arrangement for facilitating socially responsible aquaculture.⁴⁸ Further study on how community-based aquaculture can help develop social capital and how public policies and NGOs can facilitate this process is warranted.

Co-management

As aquaculture's complex socio-economic impacts involve many tradeoffs, command and control measures of policy decision-making are not likely to result in socially acceptable aquaculture development and may not even be feasible because assessment of socio-economic impacts of aquaculture is a difficult process that requires involvement of various stakeholders.⁴⁹ Thus, co-management, which is a decentralized decision-making process intended to share rights and duties among all stakeholders, has become increasingly popular in aquaculture management (FAO, 2006).

⁴⁶ While the aquaculture industry used to view NGOs as nuisances, many seafood retailers and processors have now chosen to collaborate with NGOs in enforcing market standards that promote sustainable aquaculture (Sigg, 2007; Bostick, 2008).

⁴⁷ For example, a case study in India indicated that community-based aquaculture is subject to constraints of conflicts in distribution of benefits, lack of proper leadership, lack of cooperative and democratic atmosphere, lack of proper mechanisms to allocate rights, lack of technical skills and lack of protection of the poor (De and Saha, 2005).

⁴⁸ For example, the experience of a cluster-based shrimp farming project in India indicates that group farming helped cluster farmers improve social responsibilities by information sharing; cooperation in infrastructure construction, seed selection and other activities; coordination in stocking timing and disease remedial actions, etc. (Umesh *et al.*, 2010).

⁴⁹ While the economic impacts of aquaculture development can be evaluated by monetary values based on methods such as costs and benefits analysis, social impacts (most of which are intangible) and the tradeoffs of various impacts are difficult to measure reliably by money-metric measures and hence require a more participatory approach such as the multiple criteria decision-making (MCDM) framework (e.g. the Analytical Hierarchy Process (AHP) method) (FAO, 2008b).

At the macro level, civil societies (including NGOs and producers associations) have played increasingly active roles in policy decision-making regarding resource management, capacity building, poverty alleviation, empowerment of disadvantaged groups, etc., which tends to result in more realistic and effective policies and improved implementation (FAO, 2006). At the micro level, partnerships between producers associations and scientific communities (EIFAC, 2006), between NGOs and the private industry (Bostick, 2008) and between individual fish farmers (through community-based aquaculture) have become increasingly widespread and beneficial.⁵⁰ Institutional platforms such as the Aquaculture Dialogues initiated by the World Wide Fund for Nature (WWF) have been increasingly used to facilitate communication among stakeholders.

While co-management is a promising institutional arrangement for facilitating socially responsible aquaculture, it is still at the early stage of development and yet to become mainstream. A matured co-management framework would require not only governments’ endorsement but also adjustments by all stakeholders. For example, NGOs may need to consider whether to pursue more focused social objectives and represent more specific constituencies so as to increase their efficacy in the participatory decision-making process. While co-management has thus far mainly been motivated by practical needs, further systematic research would be useful to provide insights about this institutional arrangement that has potential to help eventually achieve the goal of environmentally responsible, economically viable and socially acceptable aquaculture.

Conclusions

The above discussion has reviewed the socio-economic impacts of aquaculture based on the existing literature on the global experience of aquaculture development in the new millennium. While effort has been exerted to provide a balanced review of aquaculture’s socio-economic impacts, some equally important issues may not be discussed sufficiently due to limitation of the paper’s space and the authors’ knowledge. While evidence indicates that aquaculture development in the new millennium has been impressive and moved towards the goal set a decade ago in the Bangkok Declaration (i.e. being environmentally responsible, economically viable and socially acceptable), more systematic and comprehensive assessment based on quantitative measures is needed to assess the extent to which the goals of the Bangkok Declaration have been achieved.⁵¹

⁵⁰ For example, the Canadian Alliance for Aquaculture Reform (CAAR), an NGO association, has signed a memorandum (Framework for Dialogue) with Marine Harvest Canada (MHC) under which MHC agreed to exert efforts to reduce the environmental impacts of its operations while CAAR agreed not to target MHC in their campaigns (Bostick, 2008).

⁵¹ While indicators are useful tools for evaluating aquaculture’s socio-economic contributions (e.g. Wattage, 2010), assessment of aquaculture’s socio-economic impacts and their tradeoffs is an important yet difficult topic that entails further research effort (FAO, 2008b).

Despite the achievements, sustainable aquaculture development in the future faces many challenges such as more stringent environmental protection requirements, higher food safety standards, lack of aquaculture sites, shortage of feed and increasing energy prices, among others. Enabling public policies, more efficient regulatory frameworks, better partnerships among stakeholders, as well as other improvements in institutional arrangements are needed for aquaculture to overcome these constraints and continue developing into a mature and established industry.

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Investment, insurance and risk management for aquaculture development

Expert Panel Review 2.3

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Abstract

The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 stressed that adequate investment in aquaculture is essential for its future development. It identifies several constraints on this investment and makes recommendations for addressing the issues involved. For example, it recognizes the risk and uncertainty associated with returns from investment in aquaculture to be an important constraint on aquaculture investment. This is particularly so because insurance markets only provide very limited coverage for aquaculturists. Since 2000, research has been undertaken by the Food and Agriculture Organization of the United Nations (FAO) to address many of the issues raised in the Bangkok Declaration. This process has not been straightforward because most of the objectives for investment in aquaculture set out in this declaration are indicative rather than operational. In addition, some constraints which are not mentioned in the Bangkok Declaration have started to seriously impede aquaculture development. Economic growth generally and the expansion of aquaculture itself have resulted in increased scarcity of resources vital for the

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growth of aquaculture. For example, water has become scarcer, available new sites for aquaculture are becoming more difficult to obtain, and environmental and ecological problems of consequence for aquaculture have magnified. As a result of the latter aspect, greater regulation of economic activity, including aquaculture production is occurring. These growing problems appear to have resulted in a decline in the rate of growth of aquaculture production and are associated with a slight decline in the global per capita availability of fish. This poses new challenges for investment in aquaculture and its future growth. The future development of aquaculture is likely to depend more on the intensification of production and less on its extension than in the past. Furthermore, the future development of aquaculture is expected to become more dependent on advances in science and technology than in the past and therefore, investment in science and technology and its application to aquaculture will be of growing importance.

High levels of exposure to risk and uncertainty in aquaculture also continue to restrict investment and stunt aquaculture development. Attention is therefore given to identifying the factors that contribute to risk and uncertainty in aquaculture and methods of specifying the risk and uncertainty involved. The latter should be done by taking into account the consequences of these methods for decision-making by aquafarmers. Alternative methods of managing and coping with risk are outlined and particular attention is given to insurance of assets as a way to cope with risk in aquaculture. Ways of extending the availability of insurance cover for aquafarmers are outlined. It is found that limited practical scope exists for the extension of insurance markets in aquaculture, although with economic development it is likely that extension will occur naturally. This means that most aquafarmers will have to rely on other means to manage and cope with risk and uncertainty.

KEY WORDS: *Aquaculture, Insurance, Investment, Risk management, Sustainable aquaculture.*

Introduction

After a period of rapid expansion, the growth of aquaculture production has tapered off according to findings of the Food and Agriculture Organization of the United Nations (FAO, 2009). Probably, the most important reason for this is that vital resources needed for aquaculture production have become scarcer as a result of continuing global economic growth and a greater volume of aquaculture production. One possible way to counteract this trend is by increased and improved targeting of investment in aquaculture. *The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (NACA/FAO, 2001) recognized the vital role played by investment in aquaculture development, but at that time the decline in the growth rate of aquaculture output was not apparent. Now that it is clear, the development of sound strategies for investment in

aquaculture and for ameliorating constraints on that investment have become more important.

There are both critical constraints on investment in aquaculture (such as growing resource scarcity) and continuing constraints which have been evident for a long while. The latter include the riskiness of aquaculture as an economic activity and the difficulties which individual aquafarmers face in managing and limiting their risks. For example, there is little availability of insurance for aquaculture, and where insurance is available, it can be costly, not only because of the high level of risks to be covered but also because of the transaction costs involved in drawing up insurance policies, and the costs of monitoring risks and of processing claims. This restricts the scope that individual aquafarmers have for reducing their exposure to risks. Nevertheless, insurance is not the only potential means available to aquafarmers to reduce their exposure to risks. Therefore, in order to stimulate the development of aquaculture, a variety of mechanisms (including insurance mechanisms) need to be identified that can efficiently reduce the risks experienced by aquaculturists.

The purpose of this paper is twofold: in the light of *The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (NACA/FAO, 2001), (i) to assess advances in facilitating investment in aquaculture and remaining obstacles to such investment and (ii) to provide background on progress in the management of risk in aquaculture, to identify factors that are a source of risk and uncertainty in aquaculture, to consider the consequences of these risks for investment in aquaculture, to consider different ways of managing risks in aquaculture and in particular, to explore insurance of assets in aquaculture as a way of coping with risk. In considering the last topic, reasons for the slow development of insurance markets in aquaculture will be considered, as well as proposals for stimulating the development of these markets in an economical manner. In addition, other public policies that may be adopted to reduce the risks experienced by aquafarmers and thereby, stimulate the development of aquaculture are outlined and assessed.

Progress with strategies for investment, insurance and risk management for aquaculture development

The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 (NACA/FAO, 2001, Part V) emphasized the importance of investment both by the private and public sectors for the continued growth of aquaculture and highlighted several strategies that could be adopted to stimulate social investment in the aquaculture sector. The initiatives suggested included the establishment of “credit schemes that support sustainable aquaculture e.g. micro-credit programmes particularly for small-scale development” (NACA/FAO, 2001, p. 466). This document also mentions that “the level of risk is important when supporting initiatives to address poverty alleviation” (NACA/FAO, 2001,

p. 466). In fact, as discussed in this review, the amount of credit available to aquaculturists is limited by the considerable amount of risk which they face in their economic activities. However, the Bangkok Declaration recognizes that risk is just one of the factors that restrict investment in aquaculture and therefore, the development of aquaculture.

The FAO has produced several documents since 2000 in order to help develop strategies that will foster aquaculture development. In relation to insurance and risk management for aquaculture, these include *The review of the current state of world aquaculture insurance* (Van Anrooy et al., 2006), *Guidelines to meet insurance and other risk management needs in developing aquaculture in Asia* (Secretan et al., 2007), and *Understanding and applying risk analysis in aquaculture* (Bondad-Reantaso, Arthur and Subasinghe, 2008). In addition, *Microfinance in fisheries and aquaculture: guidelines and case studies* provides a thorough review of microfinance for fisheries and aquaculture, livelihood and micro-enterprise development opportunities for women in coastal fishing communities in India (Tietze, et al., 2007) and lists guidelines and general principles to assist those wanting to “supply microfinance services to aquaculture and for those who intend to include fishing and fish farming communities as part of the client base of their operations” (Tietze and Villareal, 2003).

The state of the world fisheries and aquaculture 2008 (FAO, 2009) pays particular attention in Part 4 to constraints on growth in the aquaculture sector and consequently, the outlook for aquaculture. It finds that while aquaculture production has grown rapidly in the last few decades, the rate of increase in its volume of production has begun to slow. This report identifies a number of factors that are contributing to this deceleration in aquaculture’s growth. These include constraints caused by the limited availability of natural resources suitable for aquaculture as well as institutional constraints. Knowledge constraints are also mentioned as limiting factors, although little consideration is given to risk and uncertainty as a factor restricting investment in aquaculture and its development. It is however, clear from this report that a combination of factors are starting to limit the rate of growth of aquaculture production. Progress in facilitating investment in aquaculture strategies to alleviate constraints on investment in aquaculture is given detailed consideration in the next section. Subsequently, risk, uncertainty and the availability of insurance markets for aquaculture are the main focus of attention because they have important implications for the amount and nature of investment in aquaculture, its development and the welfare of aquafarmers as was stressed in the Bangkok Declaration.

Research by the FAO has also identified the risk and uncertainty involved in aquaculture activities as a significant constraint on investment in aquaculture and thus, the growth of the aquaculture sector. Several papers have been produced by the FAO that throw light on the extent of this problem and the shortcomings of existing social mechanisms (such as the availability of insurance for

aquaculture) in alleviating this constraint on investment in aquaculture. Specific measures and methods that could be effective in overcoming or reducing the constraints which the presence of risk and uncertainty impose on aquaculture development have also been identified in FAO papers produced since 2000. Nevertheless, while there has been considerable progress in this matter, there is still much more to be done. The analysis of risk and uncertainty in aquaculture is a complex one, as is the development of workable procedures to moderate or allow for this risk and uncertainty in an optimal manner. This is mainly because a wide range of factors must be taken into account in addressing risk and uncertainty, as will be evident from this paper.

Objectives for investment in aquaculture contained in the bangkok declaration

What broad objectives should be pursued in investing in aquaculture?

Section 3.7 of the *Bangkok Declaration and Strategy for Aquaculture Development* sets out several objectives that should, according to the opinion of those framing it, be kept in mind when investing in aquaculture. This section mentions several general factors that should be considered when investing in aquaculture. These include sustainability, the desirability of good management, efficiency and poverty alleviation. However, the statement of such objectives is indicative rather than operational in nature. This is so for several reasons. For example, it is not made clear for whom (for which stakeholders) the objectives are desirable and whether they are considered desirable from the point of view of the aquaculture sector or from the viewpoint of society or communities as a whole. In addition, there are some other operational limitations to the way in which the objectives are framed.

For example, while sustainability may be desirable, it is necessary to specify what should be sustained and why (Tisdell, 2009b, Ch.7). Sustaining some phenomena can be undesirable. It is mentioned in Section 3.7 of the Bangkok Declaration that it is desirable to sustain aquaculture livelihoods. This may be so, but it need not always be the case. As conditions change, it is sometimes optimal for aquafarmers to exit aquaculture and take up other occupations. In such cases, adjustment of aquaculturists to altering conditions becomes an issue. More progress is needed in specifying what should be sustained in relation to aquaculture, what should not be sustained, and the extent to which the conditions for aquaculture are sustainable. Secondly it is not absolutely clear what constitutes good management in aquaculture. Although the FAO has given attention to this matter (see Secretan *et al.*, 2007), the issue is not completely resolved.

Thirdly, more precision is needed in defining what constitutes an efficient aquaculture sector. A complex set of issues are involved in dealing with this

matter. This is clear if the usual approach of economists to defining economic efficiency is adopted (see, for example, Tisdell and Hartley, 2008, Ch.2). Economists consider an economy to be efficient if it is organized in a way ensuring that its limited resources are used to minimize scarcity; that is, to satisfy human wants to the fullest extent possible given the limited availability of resources. It is usually argued that this requires productive units to exhibit technical and managerial efficiency and that resources be distributed between their alternative uses so that allocative efficiency is achieved. All of these factors are relevant when assessing the economic efficiency of aquaculture from a social point of view. However, social evaluation is even more complex because economic and other systems do not remain stationary but are perpetually changing; and the actions of human beings influence this change. Furthermore, social evaluation of possibilities does not depend on economic efficiency considerations alone.

Because human beings can and do alter economic systems as a result of research, the discovery of new techniques of production and new commodities, and innovation, systems that ensure allocative efficiency may, as pointed out by Schumpeter (1954), fail to minimize economic scarcity in the long run because they may not ensure “dynamic efficiency”, that is as much economic growth as desired. Therefore, it is apparent that what is efficient can be quite complex. The importance of strategies to invest in research and development for the advancement of aquaculture is stressed in Section 3.2 of the Bangkok Declaration, and it will be argued later that this investment is of increasing importance if increases in aquaculture production are to be sustained and falling per capita availability of fish and other aquatic products is to be avoided. Scientific research needs to be accompanied by effective development, application and diffusion of the results obtained to aquaculturists. Section 3.3 of the Bangkok Declaration outlines means for doing this.

Careful reading of Section 3.7 of the Bangkok Declaration indicates that those framing it believed that multiple objectives should be pursued in investing in aquaculture. While this may be desirable, the adoption of multiple goals also can encounter operational problems. For example, it may be impossible to satisfy all the multiple objectives simultaneously. If so, what trade-offs should be made? For example, the goal of immediately alleviating poverty could in some cases conflict with economic efficiency or economic growth goals. Issues involving dynamics need to be taken into account. For instance, should some become rich now and others remain poor in the expectation that (as a result) all will eventually become richer? General objectives for investing in aquaculture as set out in the Bangkok Declaration raise broad issues that have not yet been resolved, and which frankly, it could be difficult or impossible to resolve.

Specific recommendations (objectives) for investing in aquaculture

Several specific recommendations for investing in aquaculture development are set out in Section 3.7 of the Bangkok Declaration. It may be useful to consider the recommendations in the Bangkok Declaration for aquaculture investment in the light of economic criteria. Economists have developed criteria for assessing efficient resource-use and for suggesting circumstances in which government intervention in market systems is likely to increase economic efficiency. They point out that government intervention might be justified if (i) it increases the economic efficiency of the economic system in satisfying wants or (ii) if it improves the distribution of income, for instance, alleviates the incidence of poverty.

The Bangkok Declaration stresses that it is important for public-sector investment to complement private-sector investment in aquaculture if the full benefit of private investment is to be obtained. Public investment in capacity building, the development of institutions and in infrastructure is needed in order to realize potential returns from private investment in aquaculture. Market systems are likely to undersupply these investments because of market failures. Since 2000, transport infrastructure and infrastructure for utilities have developed rapidly in some countries, such as China and India, as a result of public investment. While these investments are not specific to aquaculture, they have assisted aquafarmers by giving them less costly access to markets for their produce and by facilitating their access to some inputs, for instance fish food and energy inputs.

Other specific suggestions in the Bangkok Declaration include:

- (i) Governments should subsidize and facilitate private investments in newly emerging types of aquaculture or aquaculture being started in new situations. In such cases, there are considerable risks, and time is required for aquafarmers to develop their managerial skills. This is a type of infant industry argument. Such intervention is sometimes justifiable on economic grounds, but it is also important that there be good prospects of the new aquaculture activities becoming economically visible in a reasonable period of time so that the subsidy can be discontinued. In other words, there must be reasonable prospects that the infant will grow up and become independent.
- (ii) Continuing public investment in rural and small-scale aquaculture in developing countries, and in applied research and farmer access to knowledge and capital are recommended. This recommendation may be supported on income distribution grounds. Also, while large private enterprises may usefully engage in research and development (R&D) for aquaculture, they are unlikely to focus on innovations of particular value to small-sized producers in developing countries because it is difficult for large enterprises to market new techniques to this group of aquafarmers. There can also be market failure in the access of aquafarmers to knowledge and capital. The limited access of aquafarmers to finance is a major issue and is discussed in later sections of this paper.

- (iii) It is also indicated that the public sector should encourage the private-sector investment in aquaculture projects and infrastructure capable of yielding community-wide benefits from aquaculture, especially to rural communities. Such projects could include processing plants for aquaculture products and cold stores.
- (iv) Another suggestion is that governments develop mechanisms which encourage the growth of environmentally and socially responsible aquaculture. With continuing economic growth, environmental spillovers (externalities) from economic activities (including aquaculture) increase in importance (see, for example, Tisdell, 2003, Chs. 1 and 28). These result in market failures and are the basis for increased government intervention in the market system. These regulations can constrain investment in aquaculture but may be justified on economic efficiency grounds.
- (v) It is recommended that governments give “support to sponsorship of industry-driven codes of practice to promote responsible aquaculture”. Whether industry standards and codes of conduct are the appropriate ones from a social point of view is debatable, but in some circumstances, the setting and enforcement of standards can overcome market failures and stimulate investment in an industry (as, for example, argued by Akerlof, 1970). However, it is often difficult to decide on the optimal standard for a product, and the required standard may vary with income levels.
- (vi) It is also said to be desirable to “establish credit schemes that support sustainable aquaculture, e.g. micro-credit programmes, particularly for small scale development”. The FAO has given particular attention to this aspect since 2000 (see, for example, Tietze and Villareal, 2003).

In addition, the Bangkok Declaration suggests that international donor resources could be more effectively employed than in the past, and that there should be greater awareness among financial institutions and assistance agencies of the contribution aquaculture can make to economic development and poverty alleviation. They should also be more aware of its financial needs.

Note that farmers involved in small-scale aquaculture operations (especially those in developing countries) find it difficult or impossible to obtain credit or finance for aquaculture. Reasons include the relatively high risk involved in such investment, the comparatively high costs involved in transacting small loans and the inability of many aquaculturists to offer adequate collateral to cover their loans. These factors are discussed later. Some of these factors also limit the access of small-sized aquaculturists to insurance. Furthermore, the inability of aquaculturists to obtain insurance adds to the risks encountered by their creditors and lenders and therefore, their disadvantage is reinforced. It should, however, be pointed out that while these factors limit the supply of credit and finance for aquaculture, they also limit the demand of some aquaculturists for credit. Many small-sized aquaculturists want to avoid debt because of the risks involved.

Although this is not mentioned in Section 3.7 of the Bangkok Declaration but referred to in Section 3.2, investment in R&D is of major importance for continuing aquaculture development, and its results are a major driver of investment in the aquaculture sector. Market failure occurs in relation to R&D and in the diffusion of its results (see, for example, Tisdell, 1981, Ch.1). While private industry can find it profitable to undertake some types of R&D and market innovations obtained from it, it does not find it profitable to undertake all R&D that is socially beneficial from an economics point of view. Both private and public-sector participation in R&D and in innovation in aquaculture is socially desirable, and an appropriate balance needs to be maintained between the efforts of these two sectors. It is argued in the next section that recent developments in aquaculture indicate that its future development is likely to become more dependent on scientific and technical progress than in the past.

Recent trends in aquaculture development: their implications for investment in aquaculture

Recent trends in aquaculture production

Since 2000, some trends (highlighted by FAO, 2009) in aquaculture production have become apparent which would not have been obvious when the Bangkok Declaration was drawn up. These trends have important implications for investment in aquaculture. While investment in aquaculture has continued to rise, it has been insufficient to sustain the rate of growth of aquaculture production.

The FAO (2009) estimates that in the period 1995–2005 compared to 1985–1995, the annual growth rate of aquaculture production fell from 11.1 to 7.1 percent. Furthermore, per capita availability of fish globally appears either to be stagnant or slightly declining because supplies from aquaculture are not growing at sufficient pace to more than compensate for lack of growth in the wild catch of fish. It could be argued that one of the reasons why aquaculture production is not growing at sufficient pace to enable increased per capita consumption to be achieved is that there has been insufficient investment in aquaculture. However, as discussed below, investment in aquaculture and returns on this investment face growing obstacles as a result of economic growth.

The FAO finds that the rate of growth in aquaculture production has tapered off both in high-income and low-income countries when each is considered as a group. Geographically, only Africa has shown an increase in aquaculture production. This, however, is mainly in North Africa and is an increase on a low base. Furthermore, the rate of growth of aquaculture production of nearly all groups of species declined in 1995–2005 compared to 1985–1995, production from marine fishes being an important exception (FAO, 2009, p.157).

The relationship between these trends and investment in aquaculture plus continuing constraints

FAO (2009, p. 153) points out:

“The popular assumption – that aquaculture production will grow as long as demand does, and do so in volumes that will virtually match demand growth – is unfortunate as it sends a surreptitious message that there is a considerable degree of automatism in the expected aquaculture response and, thus, little need for enabling public policies. Such a view of the seafood sector is misleading for those who formulate public policies towards aquaculture and capture fisheries. Aquaculture-enabling policies are essential for the steady and sustainable growth of the sector”.

It continues by stating that worldwide the rate of growth in aquaculture production is slowing. This appears mainly to be because aquaculture is facing tightening constraints because of increasing scarcity of some of its vital resources. This development poses growing challenges for “public administration that uses public resources to promote continued aquaculture growth” and makes it more difficult (overall) for aquafarmers to add to their productivity and to maintain their returns by undertaking extra investment in aquaculture.

An important influence on this trend is the operation of the law of eventually diminishing marginal productivity or diminishing marginal returns (see Tisdell, 1972, Ch.7). The law of diminishing returns comes into force when some of the required resources for production of commodities (such as aquaculture produce) become limited in availability and/or when this is so for its more productive resources and the expansion of production must increasingly rely on the growing utilization of inferior resources. Industries such as aquaculture and agriculture are increasingly subject to this law. This law operates in the absence of offsetting influences, such as technological and scientific progress, which tend to raise productivity.

In relation to aquaculture, growing resource constraints include the increasing scarcity of the availability of water for aquaculture (due to increased competition between aquafarmers and others for water supplies) and increased competition for the use of land and aquatic space due to economic development.

The expansion of aquaculture was initially driven by both the profitability of its expansion to new areas and its intensification in areas already used for aquaculture. Further extension of aquaculture is becoming more difficult, and the returns on its extension appear to be declining in those areas and fields of aquaculture that are relatively mature. Less scope exists than previously for the areal expansion of aquaculture. Therefore, in the future, there will need to be greater reliance on the intensification of aquaculture to raise its yields. This will call for greater investment in R&D and require more capital-intensive aquaculture. In turn, greater levels of investment will be needed in existing

aquaculture enterprises. Although scope may still exist for the areal expansion of aquaculture in sub-Saharan Africa and Latin America, as suggested in FAO (2009), this expansion will not be without difficulties.

A further constraint on aquaculture growth in developing countries, such as China, which are major producers of aquaculture products is that with their economic development, opportunities of farmers for earning income off-farm are likely to increase. As a result, the availability of rural labour for aquaculture can be expected to decline. To some extent, this might be compensated for by the substitution of capital for labour in aquaculture and by an increase in farm sizes. Clearly, in such cases, the availability of funds for investment in aquaculture is important.

In addition, as a result of economic growth, including the growth of aquaculture itself, several environmental and ecological problems are emerging which are limiting the expansion of aquaculture and the returns obtained from it (see, for example, Tisdell, 2004, 2007, 2009a). Lack of social acceptability towards some forms of aquaculture, particularly site allocation, also inhibits its expansion. Social acceptability is likely to become a growing constraint. While environmental regulations designed to manage such effects may restrict investment in aquaculture in the short run, they are sometimes necessary to maintain its returns on investment in the long run. Environmental and ecological policies can be expected to have a major influence on investment in aquaculture in the future.

Environmental and ecological policies for the regulation of aquaculture need to be balanced, well-designed and based on relevant scientific evidence. Otherwise, they may unnecessarily restrict investment in aquaculture and its growth even when its expansion is socially worthwhile and sustainable. Furthermore, severe environmental restrictions in some countries or regions may result in investment in aquaculture shifting to other countries and regions where it is subject to little or ineffective control. In some instances, this can increase global environmental damage. Clearly, the environmental regulation of aquaculture involves complex considerations. While aquaculture developments should not be allowed to take place without concern for the environment, a balanced approach needs to be adopted when giving weight to environmental considerations. Nevertheless, differences in opinion make it difficult to determine the appropriate balance, such as in the case of restrictions imposed by the Ghanaian Environmental Protection Agency on the use of improved tilapia stocks in Volta Lake (Hynes, 2008). Some individuals believe this is overzealous, whereas others obviously do not. Similar examples can be found elsewhere.

The above outlines important trends and dynamic consequences for future investment in aquaculture. There are also some continuing constraints on investment in aquaculture. These include lack of security of property rights and the riskiness of investment in aquaculture.

When property rights are absent, insecure or limited (e.g. the transferability of property is limited), this adversely affects investment that is based on the use of such property (Tisdell, 2009b, Ch.4). Property may be insecure because it is not backed up by legal title and in some communities, there can be lack of respect for private property. Property rights vary from country to country but are weak in some jurisdictions for sites used for aquaculture. When property rights are weak, this reduces private investment and lowers the suitability of properties as collateral for loans, which further adds to lack of investment. However, there are in addition, many other factors that can be important sources of risk and uncertainty in aquaculture and consequently, can have a negative impact on investment in aquaculture. These are continuing problems which will now be considered.

Identification of factors contributing to risk and uncertainty in aquaculture

Shared water resources

Although many forms of agriculture are considered to be quite risky from an economics point of view, it is widely believed that aquaculture is, on the whole, much riskier than agriculture (see for example, Secretan *et al.*, 2007). This is primarily because aquafarmers have only partial control (and in some cases, no control) over important variables that influence their yields. For example, the water that aquafarmers use often has to be shared with others and individual aquafarmers at most only normally have little control over its quality and its availability to them.

Variations (which are often difficult to predict) in the quality of shared water (such as alterations in its temperature, its dissolved oxygen content, its nutrient content and the extent to which it transmits pollutants and diseases) influence the growth rates and survival of many aquacultured species, thereby affecting the productivity of aquaculture. Some of these effects are evidenced by changes in the morbidity and mortality of farmed aqua-stocks. Compared to aquaculture, production in agriculture (and in many other industries) is less influenced by events that are not controlled by individual producers. This is mainly because producers in these industries rely less heavily on the use of shared resources to produce their output.

Of course, not every undertaking in aquaculture depends on the use of shared water resources. Sometimes aquaculture occurs in ponds, each of which belongs to a single farmer. But even in that case, the quality of the water in each separate pond may be subject to fairly unpredictable changes. Where production occurs in tanks and constructed raceways and water supplies are pumped to these, some monitoring of water quality is possible. Where water is being recirculated so that the aquaculture system is relatively closed, scope exists for greater control of water quality, but such intensive systems tend to be costly and are not economically feasible for most aquafarmers.

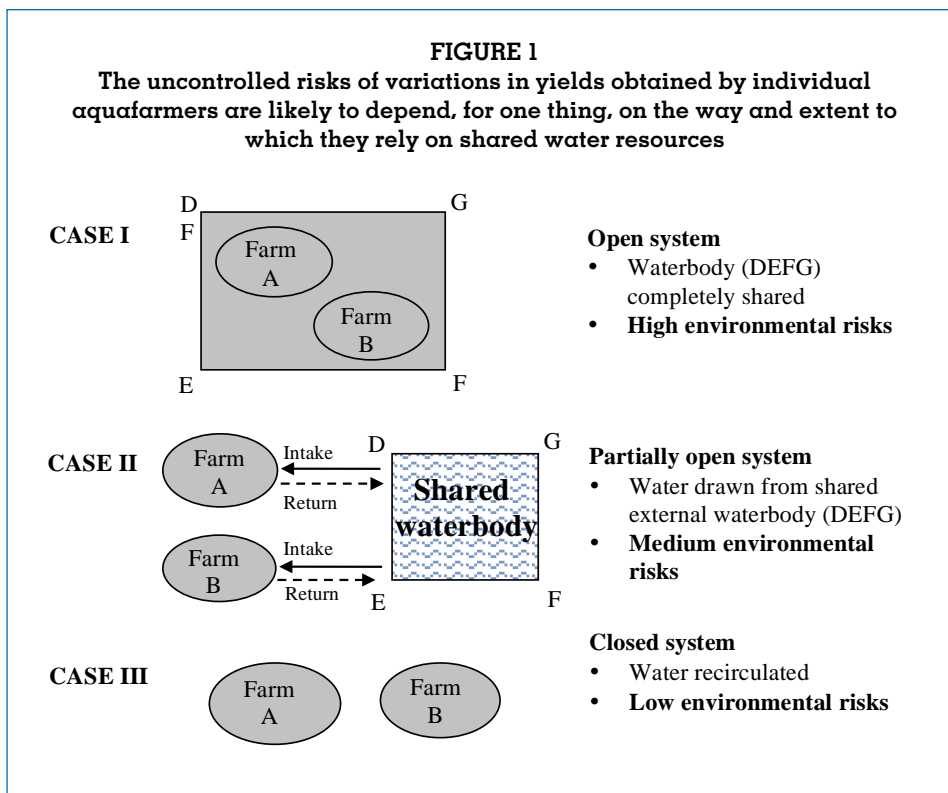
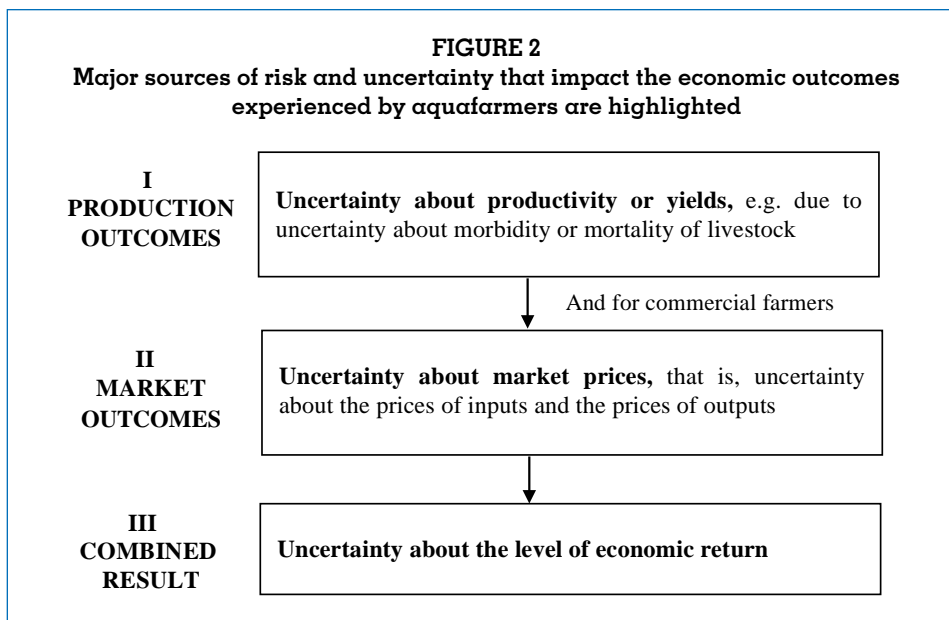


Figure 1 indicates how environmental risks affecting yields in aquaculture vary with the way in which aquafarms depend on external water supplies for the culture of their stock. It is possible that as aquaculture becomes more intensive that the degree of control that aquafarmers are able to exert on their yields will increase.

Market conditions

If an aquaculture enterprise is market-oriented, it also faces risks associated with variations in its market conditions, i.e. uncertainty about changes in the price of its product or of alterations in the price of its purchased inputs. Whether this source of uncertainty is greater in aquaculture markets than in other types of markets, such as in agricultural markets, is not known; but it is a matter that could be investigated.

The extent of uncertainty about economic returns from aquaculture is the combined result of uncertainty about yields and market prices. Figure 2 highlights this. While all the risk elements shown in Figure 2 apply to market-oriented aquafarmers, only uncertainty about production outcomes is relevant to subsistence aquafarmers who do not trade.



Specifying the extent of risk in aquaculture and the consequences of risk for decision-making

Risk specification

The extent to which and how the lack of certainty about important variables affecting aquaculture outcomes can be specified quantitatively varies according to circumstances. For some variables, it may be possible to specify a probability distribution with a reasonable degree of accuracy, but sometimes this is not possible. If uncertainty is considerable, it may only be possible to specify outcomes (and possible payoffs) that may occur but not the probabilities of these outcomes. Intermediate cases are also possible. For example, it may be possible to specify the probabilities of some events occurring but not all.

If reasonably accurate probability distribution for relevant variables can be specified, then use can be made of statistical analysis to derive the relevant consequences of aquaculture decisions. One, however, needs to consider whether the probability distributions are based on objective probabilities, such as empirically based relative frequencies, or on subjective or personal probabilities, for example, those suggested by an “expert”.

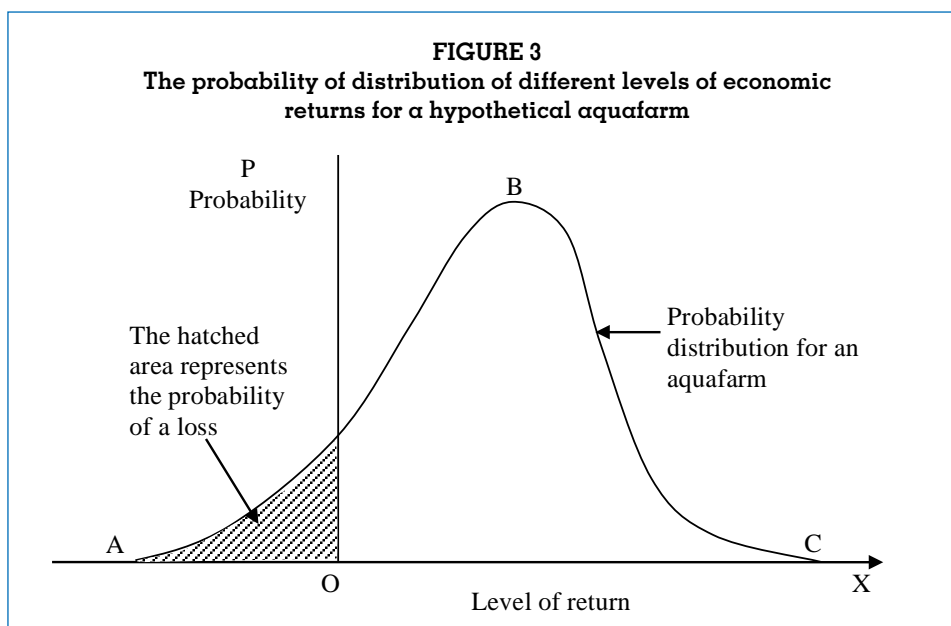
It can be very difficult to obtain empirically derived probabilities for some variables affecting aquaculture because their probability distributions are not stationary. Nevertheless, the longer an aquaculture industry has existed and therefore, the greater its experience with it, the more reliable are likely to be the estimates of its relevant probability distributions.

When a reliable probability distribution of returns for an aquafarm can be obtained, then it is possible to specify the probability that its returns will fall below a specified level, for example the probability that its returns will be negative. For instance, given the bell-shaped probability distribution shown in Figure 3 by the curve ABC, the probability of negative returns is equal to the area of the hatched area shown.

For instance, this probability of distribution can be used to specify the likelihood of the farm incurring a loss. This type of approach has been adopted by Weston, Hardcastle and Davies (2001) to specify the probability of model aquafarms (farming different species) making a loss, and the probability that model aquafarms of different sizes (based on their volume of output) will make a loss when farming the same species. In their modeling, Weston, Hardcastle and Davies (2001) find for most species investigated by them that farms of larger size are less likely to make a loss because of their economies of scale.

Frequently, however, probability distribution cannot be well specified. In such cases, it can be useful for aquafarmers to have information on the sensitivity of their yields and returns to variations in important variables. This information can be catered for by scientists; they can perform sensitivity analysis and communicate the results to farmers.

Information may also be conveyed by specifying outcomes and payoffs for several alternative scenarios that are believed to be possible. Outcomes, and consequently payoffs, are based on assumptions about alternative possible events or states of nature, and this information may be conveyed in matrix form, as in game theory.



Nevertheless, it should be recognized that the process of risk analysis and its application to aquaculture involves several components. The four major components which Arthur (2008) identifies include hazard identification, risk assessment, risk management and risk communication.

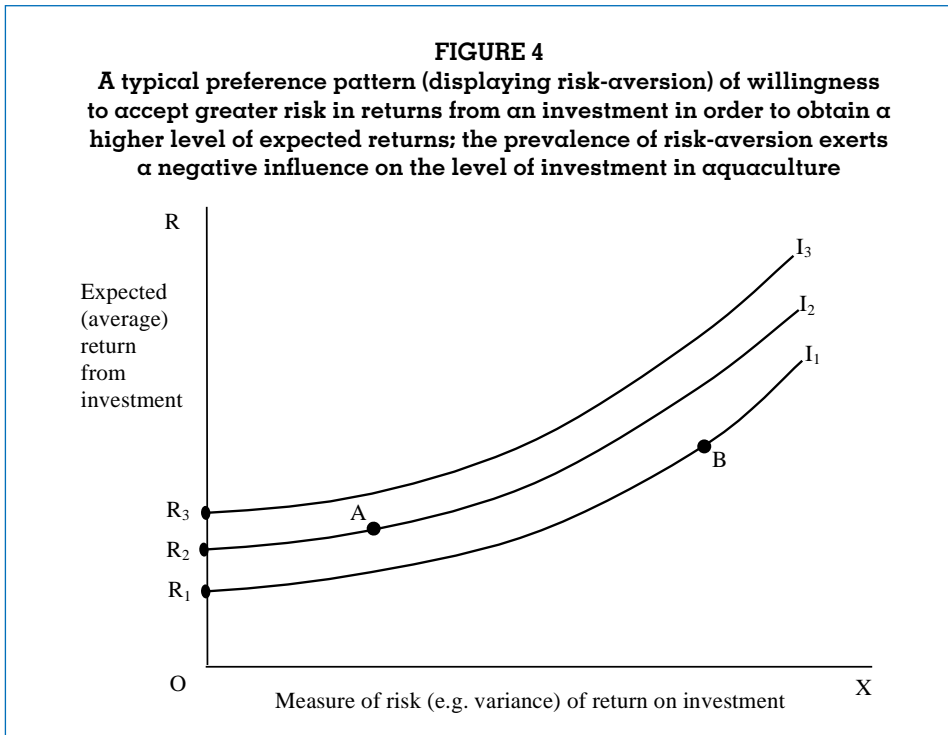
It is necessary to determine what the important hazards are in aquaculture, how best to specify the risks involved and their consequences, and in addition, to determine the best ways to manage or cope with these risks. An allied problem is how to communicate effectively to aquafarmers the risks involved in aquaculture activities and the ways in which they can manage these. Advances in information about any of these components can help to reduce the risks faced by aquafarmers.

Consequences of risk for decision-making: investment in aquaculture

The nature of decision making when uncertainty exists depends on how well the uncertainties involved can be specified and on the attitude of decision-makers to the bearing of risk and uncertainty. It is believed that most economic decision-makers are risk-averse. The nature and level of risks and uncertainties associated with aquaculture restrict investment in aquaculture and retard the development of aquaculture because of the reasons specified below (see also Tisdell, 2012).

The comparatively high risks associated with aquaculture and problems in obtaining secure collateral for loans and credit, limits investment in aquaculture. Figure 4 illustrates the way in which risk-aversion is detrimental to investment in aquaculture. Suppose a landholder has a choice between an aquaculture project having a level of expected return and risk corresponding to point B in this figure and an alternative agricultural project having a return corresponding to A. Risk-aversion of the landholder is represented by the upward-sloping indifference curves identified by I_1 , I_2 and I_3 . Risk-and-return possibilities on higher indifference curves are preferred because these give higher returns on average for the same degree of risk. The certainty equivalent returns corresponding to each of the indifference curves shown are respectively R_1 , R_2 and R_3 . The certainty equivalent return for project A is higher than that for project B. Therefore, the landholder will prefer to invest in project A rather than in project B, even though project B gives a higher expected level of returns; the aquaculture project is not favoured because of its greater risk of loss on return on investment involved for construction of new tanks or ponds.

Income levels also restrict investment in aquaculture. This is because risk-aversion is, as a rule, inversely related to income. Low-income earners are generally more risk-averse than individuals having higher incomes. For instance, many small farmers in developing countries adopt a safety-first approach to investing. This approach may dominate their investment decisions. In particular,



they may only be prepared to undertake investments that result in a very low probability of their income falling below subsistence level. Therefore, they mainly try to avoid risky investments in aquaculture. This attitude contributes to under-investment in aquaculture when the level of investment is assessed from a social perspective.

A further factor that contributes to under-investment in aquaculture from a social point of view is the lack of availability of credit and finance. Lack of suitable collateral compounds the problem. The collateral aquafarmers can offer for loans or credit gives little security to lenders or creditors and makes them reluctant to lend. In many instances, the main asset of aquafarmers is their livestock. The size and value of this stock varies considerably with the passage of time. Thus, it is difficult for lenders to realize the stock in the event of foreclosure. Furthermore, when property rights in land and water spaces used for aquaculture are insecure or absent, this further reduces their collateral for loans.

Another relevant factor is the small size of the farms. The costs of securing collateral in relation to aquaculture are relatively high. The comparative transaction costs involved in arranging loans usually decline with the size of the aquafarm seeking finance. Consequently, there is less availability of finance for those involved in smaller aquaculture operations than in larger ones. In addition, because of their high level of risk-aversion, many small-scale aquafarmers want

to avoid loan commitments. All these factors have adversely affected the level of investment in aquaculture.

It was also observed above that lenders are less knowledgeable about the aquaculture sector than they are about the agriculture sector. Consequently, they can be reluctant to finance aquaculture projects. Similarly government policy can constrain investment and the availability of finance for aquaculture. For example, the failure of governments to provide long-term leases for the use of waterbodies reduces the availability of finance for aquaculture, creates uncertainty and can result in poor environmental practices.

The availability of insurance is another important determinant of investment in aquaculture. When aquafarmers are able to insure their assets, this provides greater security to potential lenders. Nevertheless, as discussed later, there are many obstacles to the development of insurance markets in aquaculture. Several of these obstacles are similar to those experienced by potential lenders to aquafarmers.

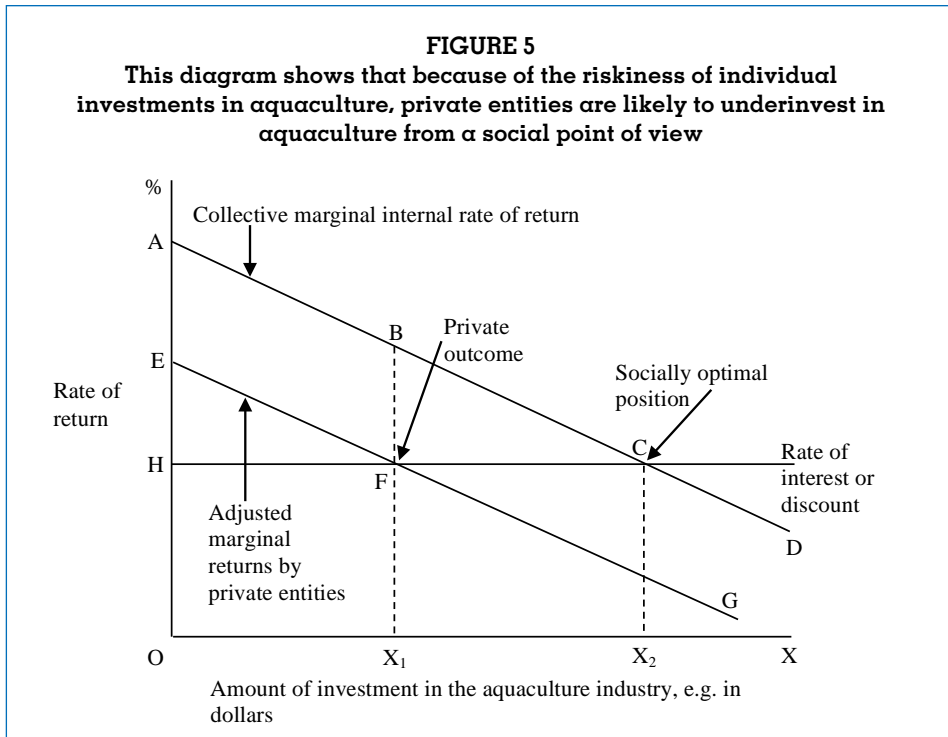
In summary, from a social economic point of view, investment in aquaculture is limited because of the considerable risk involved, and farmers tend to be risk-averse; the collateral that aquafarmers can provide for credit and loans is insecure, which reduces the willingness of creditors and lenders to provide them with credit or loans, and insurance is not available for many aquaculture activities, or they can only be insured at a high cost, which dissuades many aquafarmers from insuring.

Methods of risk management and investment increase in aquaculture

Background

When the economic returns from risky investment activities of individual entities in a group are not perfectly correlated, their collective risk is less than the risk experienced by the individuals in this group. This can form a basis for collective risk-sharing, e.g. via insurance. In fact, if the number of individuals is very large, their aggregate returns will show little or no variation if the levels of their individual returns are not correlated. As pointed out by Arrow (1965), the collective gains to society from investment can be increased by expanding the level of investment in industries which exhibit high levels of risk on individual investments but lower levels of collective risk, that is by expanding it compared to the level of investment which would occur under free market conditions. This can be illustrated by Figure 5.

In this figure, line ABCD represents the collective marginal internal rate of return from investment in an aquaculture industry. For simplicity, this is assumed not to be stochastic because of the law of large numbers and lack



of correlation between the returns experienced by individual aquafarmers and their investments. However, because individual aquafarmers do experience risk, they adjust their returns downward to allow for this risk. The internal rates of return on which aquafarmers base their decisions are their certainty equivalent returns; that is, their expected returns adjusted for risk (see Figure 1 and its discussion). Aquafarmers act as if the marginal internal rates of return on investment are as indicated by line EFG.

Assuming that a discount rate (e.g. a rate of interest) of OH exists, aquafarmers will want to invest X_1 in aquaculture. However, from a social point of view, it is optimal to invest X_2 in the industry. This implies that, from a social point of view, there is insufficient investment in the industry. This low level of investment is due to the risks faced by individual aquafarmers. Collective economic returns could be increased by a higher level of investment in aquaculture. Both institutional and non-institutional measures can be used for this purpose.

Institutional measures

Institutional measures that can be used to manage risks in aquaculture include some that are easily altered by government policies and others that are more difficult to change.

Governments can adopt a variety of policies to counteract under-investment in risky aquaculture activities. These include subsidies for investment in

aquaculture; they reduce risk to farmers. However, in assessing the desirability of this approach, there is a need to take account of the costs of administering such a scheme. If these costs are too high, subsidy schemes will not be economic from a social point of view.

Other public policies that could reduce the riskiness experienced by those investing in aquaculture include provision of extension services. By providing aquafarmers or potential aquafarmers with information that reduces their uncertainty or by making aquafarmers aware of management techniques that can reduce their exposure to risk, extension services will counteract underinvestment in aquaculture.

Important institutional features include available forms of ownership of an enterprise, the nature of property rights (including the security of property), the size of the enterprise, the extent of market development and the country's macro-economic development level.

Regarding the forms of ownership, individuals can often reduce their risks by sharing their risks with others. The public company form of ownership, especially when combined with limited liability, can be an effective means of reducing the risks of investors. However, this form of legal entity (a public company) is not usually within reach of small enterprises, be it elsewhere or in aquaculture; sole ownership continues to expose small enterprises to the greatest risk. To reduce these risks, small enterprises can consider the private company limited liability, partnerships and co-operative forms of ownership or self-help microfinance groups.

It is important to emphasize that none of these ownership forms is always an economic option for very low-income enterprises, as is often the case in developing countries. In addition, although the above forms of ownership facilitate risk sharing, they can expose partners to these arrangements to new risks. For example, principal-and-agent problems can arise in the case of public companies. The co-operative forms of ownership may also be cumbersome and can be plagued by free riding by members of the co-operative, but in recent years formation of self-help groups in Asia and providing credit through microfinance have shown encouraging results for developing aquaculture on a small scale.

The nature of property rights is also important in risk management. Greater security of property rights lowers the risks taken by individual investors and in turn, this is likely to improve their credit prospects. Increased security of property rights and a reduction in the costs of enforcing these rights can help stimulate investment. Note that apart from the legal status given to property rights, the social respect that individuals have for such rights is an important consideration and depends on the prevailing morality (ethics) of society.

Full property rights only exist if the possessor of the property has exclusive rights to use it and enjoy its produce, and if the possessor is able to transfer it without impediment (Tisdell, 2009b, pp. 103–104). If others can take the produce of the property, this reduces the benefit obtained by the possessor from investing in the property. If a property cannot be transferred or easily transferred, it is of little value as collateral for loans because investment in it cannot be recouped by its sale. These factors reduce the willingness and ability of possessors of property to invest in it.

The extent of market development influences, among other things, asset leasing possibilities and insurance availability. Leasing of assets provides a means by which aquafarmers can reduce their exposure to risk and to some extent, counteract a shortage of available credit and capital. For example, leasing of equipment or land reduces the extent to which investible funds are locked into an enterprise and lowers the level of possible sunk costs of the aquafarmers should their aquaculture enterprise be unsuccessful. The extent to which leasing arrangements have developed in relation to aquaculture is not well documented. The property rights need to be given for long-term lease, i.e. for the period of loan repayment of 10–15 years.

The development of markets for leasing assets is, in turn, influenced by the institutional arrangements that prevail in society. Taking into account market transaction costs, larger enterprises are more likely to have access to leasing arrangements than smaller ones.

Insurance provides another means of coping with risks in aquaculture. Its availability and costs are influenced by institutional factors and market transaction costs, as well as by the inherent risks faced by the insurer. The availability of insurance for aquaculture activities is very restricted, and it is more likely to be an available option for larger-sized enterprises than for smaller-sized ones (Secretan *et al.*, 2007). Insurance as a means of coping with aquaculture risks will be discussed further in the next section.

The size of the enterprise is important in managing and coping with risks. In general, it is more difficult for smaller-sized aquaculture enterprises to reduce their economic risk than for larger-sized ones to do so. Large aquaculture enterprises spread risks by locating in different geographical areas or through diversification of their products; they are able to average out their risks to some extent. They may also find it more economical to collect information than small-sized enterprises. As discussed earlier, improved knowledge can be used to reduce risk.

A country's macro-economic development level is one of the many other different influences on managing and coping with risk in aquaculture and for which the available methods and the economics of use can vary with the institutional

framework in which aquaculture occurs. For example, aquaculture enterprises with headquarters in higher-income countries may have greater access to mechanisms, such as more secure property rights, to spread their risk than most aquaculture enterprises in lower-income countries. Enterprises originating in higher-income countries are also likely to have greater scope to insure their investments than those based in developing countries. Whether or not they find it easier to be granted limited liability and are more commonly able to spread their risks by company forms of ownership is unknown, but it is probably the case.

Aquaculture enterprises in lower-income countries find it more difficult to reduce their risks than comparable enterprises in higher-income countries, partly because market systems are less developed in low-income countries. Furthermore, because small enterprises dominate aquaculture production in lower income countries, this restricts opportunities to reduce risk in aquaculture in lower-income countries. However, formation of self-help groups can reduce the risk in aquaculture.

Non-institutional measures

There are also several measures that do not rely on the institutional structure of society and which aquafarmers can adopt to cope with risk. These include product diversification and in some instances, the opposite, namely greater specialization in production. They also include retaining flexibility in business operations (e.g. by reducing the use of fixed and sunk capital), limiting their exposure to loans and credit, collecting greater information, engaging in precautionary action, and undertaking well-timed and appropriate remedial actions to limit risks should they emerge. However, all of these measures involve costs that must be weighed against their benefits.

The extent to which the use of these measures is rational involves complex considerations. For example, on the one hand, if the returns from producing different products are not perfectly correlated, product diversification tends to reduce variations in economic returns, which reduces risks. On the other hand, product diversification may result in average returns falling if there are economies from specialization in production. Moreover, product diversification may lead to a general lowering of skills and knowledge about the supply of products produced, and thereby, lends truth to the adage that a “jack-of-all-trades is a master of none”!

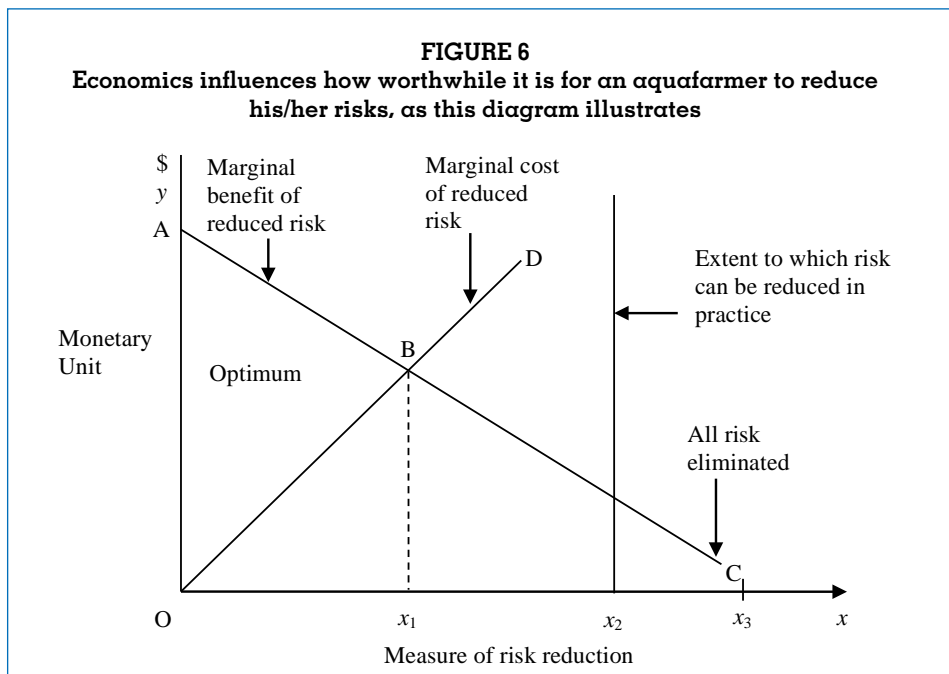
In addition, an aquaculture enterprise can sometimes reduce its risks involved in farming a particular species by specializing in only some stages of its production. For example, some aquafarmers may be able to reduce their production risks by purchasing fingerlings rather than rearing these themselves.

Two of the above mentioned points concerning risk management are worthy of further consideration, namely limits to the economics of risk reduction and decisions to buy-in inputs rather than to produce them in-house.

Economic limits to risk reduction are illustrated by Figure 6. There, y indicates monetary value (for example, in dollars) and x is a measure of the extent to which risk can be reduced by an aquafarmer by adopting a relevant action (for example, by buying insurance). The value x_3 corresponds to a situation in which all risk is avoided; but it may be impossible to reach this point. In the case illustrated, the greatest extent to which risk can be reduced is designated by x_2 . The line ABC represents the marginal benefit that the aquafarmer places on risk reduction and the line OBD indicates the marginal cost to the farmer of achieving risk reduction.

In practice, as the risk reduction increases and approaches x_2 , the latter (the marginal cost to the farmer of achieving risk reduction) is likely to escalate. If the fixed or overhead costs of reducing risk are not too high, then the most economic level of risk reduction (in the case illustrated) corresponds to point B, and a reduction in risk of x_1 maximizes the net economic benefit achieved by the aquafarmer from taking action to reduce risk. This highlights the point that risk reduction by an aquafarmer needs to take into account economic considerations. In the case illustrated, it is uneconomic for the aquafarmer to reduce his/her risk to the full extent possible.

Sometimes, it is more economical for governments to adopt measures to reduce the risks experienced by individual aquafarmers than for them to adopt individually measures to reduce their risks. For example, while buying in inputs rather than producing them in-house is an economic option, it can expose the buyer to added



risks. For example, it may be difficult for a buyer to judge the quality of seed or fingerlings, or of purchased feed, and costly for each aquafarmer to carry out the necessary checks. There is a problem of asymmetry of information between buyers and sellers (Van Anrooy *et al.*, 2006, p. v). The seller knows the quality of the product being sold, but it can be difficult for a buyer to judge this quality. In such circumstances, the government may require accurate disclosure by the seller of the characteristics of the product to be sold, and treat serious breaches of this requirement as a criminal offence. However, compliance is not always guaranteed. Alternatively, government bodies or trusted private bodies may test and certify products. These approaches can be more economical than leaving buyers (aquafarmers) to deal individually with this riskiness of quality problem.

There are also other circumstances in which a public approach to risk reduction is more economic than similar action by individuals. For example, it may be more economic for public bodies to collect information (and disseminate it) than for individuals to attempt to gather information. Government action is usually the most economic way to deal with collective risks that can, for example, arise as result of the outbreak of a communicable disease or the introduction of an exotic pest or disease to a country. Government action may be required and can be economic as a means to guard against risks associated with environmental spillovers, such as the possible release of pollutants into waterbodies. All the above-mentioned risks are likely to reduce investment in aquaculture unless they are contained.

Natural disasters are particularly costly to aquaculture. Reducing the risks involved and coping with the aftermath of such disasters requires public preparedness of the type outlined in Westlund *et al.* (2007).

It is safe to conclude that ways of addressing risk and increasing investment in aquaculture are multidimensional and involve complex considerations. As mentioned earlier, insurance provides a potential means for aquafarmers to reduce their exposure to risk. It is, nevertheless, just one possible means by which an aquafarmer can reduce his/her exposure to risk. Furthermore, insurance is not always an ideal means of addressing risk and uncertainty in aquaculture. Let us consider this matter in some detail.

Insurance of assets in aquaculture as a way of coping with risk

Lack of insurance markets for aquaculture, especially small-scale, and constraints on their development

The availability of insurance for aquaculture is limited compared with its availability for other industries and especially so for aquafarmers in developing countries (Van Anrooy *et al.*, 2006; Secretan *et al.*, 2007). The main reason is the high transaction costs incurred in assessing risks in each individual case,

checking the compliance of aquafarmers with the conditions of an insurance policy and assessing their claims. The risks involved in aquaculture can be relatively unstable, which makes it difficult to determine an appropriate level of insurance premiums.

In order to assess risk, a risk surveyor needs to visit each aquafarm seeking insurance and determine the risks involved and the conditions to be attached to a policy. The comparative expense involved in this is higher for smaller-sized farms than for larger-sized ones. In addition, generally an aquafarmer is expected to report changed environmental conditions that may lead to claims as soon as they emerge (for example, evidence of a disease outbreak in the stock) and to take appropriate defensive action. This may require a visit by an insurance loss adjuster, which adds to the insurer's costs. Furthermore, if a claim is made, on-site assessment of it is usually needed. All these costs tend to be relatively higher for smaller entities buying insurance coverage. It may also be that differences in management practices result, on the average, in the likelihood of claims being higher for smaller-sized aquaculture farms than for larger ones. For example, on smaller farms veterinary services are less affordable than on larger farms.

For these and other reasons, the insurance premium paid by aquafarmers can be expected to increase with the amount of insurance coverage purchased, but at a decreasing rate. In addition to variations in premium levels, deductible levels are often higher for smaller insurance claims. Deductions of 20 to 25 percent of the total stock loss are common. This means that, if available, insurance coverage is likely to be relatively more expensive for smaller-scale than larger-scale aquafarmers. In fact, premiums are likely to be so high that most small-scale aquafarms find insurance uneconomic, particularly insurance of their livestock. For most aquafarmers, their living stock is their major asset.

There are several reasons why it is difficult or often impossible to insure aquatic livestock. First, it can be difficult to estimate the size and value of this asset because it cannot be easily seen. The insurer, therefore, relies on proper stock purchase invoices and proof of reliable stock accounting principles. Secondly, with the passage of time, the amount and value of the stock alters, which should be covered in the stock accounting systems by the registration of daily morbidity, and intermediate harvests of stock. Thirdly, should a loss occur, it can not only be difficult to verify the amount of the loss, but assessment of the loss must be made quickly before the evidence disappears, for example, in the case of dead fish before they decay. Insurance of more permanent assets such as buildings and equipment is easier because the above mentioned problems are usually absent. Local public authorities may require the rapid disposal of dead fish. This is generally carried out by weighing the dead mass and burying the dead fish in a pit. When local authorities manage this disposal process, they can provide the aquafarmer with written evidence of his/her loss. Nevertheless, the worth of this evidence depends on the honesty of those involved in the process.

Exposure to moral hazards in relation to insurance for aquaculture can also be high (Van Anrooy *et al.*, 2006). It can be difficult or costly to determine whether an aquafarmer has complied with all the management conditions incorporated in an insurance contract. Where there is insurance against theft, traceability can also be problematic. In order to reduce their exposure to moral hazard, insurers usually only cover a part of the possible loss of an asset and require its owner to carry some of the risk. In other words, an insurer usually requires co-insurance by the insured. This is reflected in the deductible amount of the policy. Only claims in excess of the deductible amount are subject to the insurer's scrutiny.

The extent to which co-insurance is required normally depends on the extent to which moral hazard and asymmetry of information exist about the risk being covered. Because of the extent of these problems in insurance for aquaculture, the proportionate level of co-insurance required of aquafarmers by insurers is likely to be high. A high level of co-insurance adds to the relative cost of this type of insurance because of the high fixed costs involved in issuing and evaluating these types of insurance policies.

There have been suggestions that groups of small-scale aquafarmers by forming suitable co-operatives might overcome some of the obstacles to their access to insurance. For example, a co-operative may establish administrative and veterinary arrangements for the group which satisfy the expectations of insurers, thereby reducing premiums or the level of deductibles. Furthermore, some of the costs of loss and risk assessment may be borne by the co-operative itself. These groups could have similar functions to those groups formed to facilitate micro-financing.

Two other features of insurance for aquaculture can be noted. Given the importance of asymmetry of information, settlement of claims based on aquaculture policies are dispute-prone. This can add to the cost of insurance for aquafarmers because insurers need to make allowance for the probable costs involved in settlement of disputes about claims. Insurers have an interest in minimizing these costs and therefore, often favour arbitration as a means of dispute resolution rather than recourse to the legal system. Secondly, the extent to which claim dispute problems are likely to occur depends on the prevailing morality and ethics in societies. For example, the greater the degree of honesty, the lower are likely to be the insurance premiums and the level of deductibles. In addition, insurance coverage may be extended to aquafarmers who have integrated veterinary support and who demonstrate that they have reliable stock accounting systems.

Hybrid insurance schemes

Secretan *et al.* (2007) and Van Anrooy *et al.* (2006) provide a valuable introduction to insurance and risk management in aquaculture generally. In particular, Secretan *et al.* (2007) explore the possibilities for cooperation

between commercial insurers, governments and non-governmental organizations (NGOs) as a way to extend the insurance coverage available to aquafarmers and reduce their exposure to risks. At the same time, they identify several important factors that limit the availability of insurance cover to aquafarmers, particularly small-scale aquafarmers. These factors result in seemingly high insurance premiums, but these premiums actually are a product of underlying costs, such as the high market transactions costs involved in arranging and managing insurance for aquaculture.

One of the possible policy innovations explored by Secretan *et al.* (2007) is the introduction of hybrid insurance schemes. They propose that commercial insurers and governments, and possibly NGOs, cooperate to extend the amount of insurance coverage to aquafarmers. Commercial insurers would cover risks for which insurance is commercially viable, with other parties covering risks of social concern but which are not commercially insurable. More specifically, the hybrid approach proposes that “public bodies use their resources to provide social coverage, but on a basis that is coordinated and compatible with the insurance sector’s approach and that follows its information gathering, inspection and survey and loss adjusting processes.”

This approach is suggested as a method likely to reduce insurance transaction costs, extend insurance services to small-scale aquaculture farmers and “decrease and better manage aquaculture-related risks at the farm level”.

While such schemes could be socially attractive, their economic consequences depend upon the form they take. As pointed out in Secretan *et al.* (2007, p. 5-8), there are numerous ways in which hybrid insurance can be structured between insurers and governments. For more information about this aspect, the reader is referred to Secretan *et al.* (2007). However, it is worth noting that Secretan *et al.* (2007) considers three possible types of hybrid schemes:

1. the government provides coverage (*gratis*) beyond that which commercial insurers are prepared to provide;
2. the government subsidizes the insurance premium to be paid for cover; and
3. the government provides coverage for particular perils (such as floods or typhoons) for which insurers are not prepared to provide coverage.

The extent to which hybrid schemes have developed since they were suggested is unclear. However, before their translation into policy and their implementation, some of their aspects probably need further deliberations. For example, would an aquafarmer be required to have commercial insurance as a precondition for being eligible for the social insurance provided by a hybrid insurance? If so, those aquafarmers who cannot afford commercial insurance or who prefer to cover their own risks may be resentful of their comparatively lower risk cover. Furthermore, hybrid schemes will tend to increase the demand for commercial insurance. In

particular cases, a higher demand for this type of insurance can lead to a part of the economic benefit of the scheme being appropriated by insurers. This is most easily seen on the basis of standard economic theory if it is assumed that the government subsidizes insurance premiums (see, for example, Tisdell and Hartley, 2008, pp. 117–119). On the other hand, if there are strong economies of scale in the provision of commercial insurance, insurance premiums could fall. These theoretical possibilities are explained in Appendix 1. Empirical studies are needed to determine what is likely to occur in practice.

An additional matter requiring consideration is the suggestion that the commercial insurance industry should act as an agent or part agent of the government in assessing social insurance claims. While this can potentially reduce administrative costs involved in the management of hybrid schemes, it raises potential principal-agent issues of the type mentioned, for example, by Williamson (1975). For instance, how are agents from the commercial insurance industry to be compensated for their extra effort in assessing social insurance claims and how is their performance to be monitored.

Further discussion of issues involved in insurance and risk management

One of the economic benefits claimed for hybrid insurance schemes, and insurance generally, is that they promote better management by aquafarmers (Secretan *et al.*, 2007). The main way in which this better management is believed to be achieved is by insurance brokers and insurers placing conditions on the management practices of aquafarmers to enable them to qualify for insurance coverage. While such conditions reduce the risks to the insurer, it is not clear that they necessarily result in better management practices from a social economic point of view. There can be different tests of what constitutes a better management practice, and the relevant tests need to be specified and debated. Also, it needs to be kept in mind that increased insurance coverage and intervention by the insurance industry in aquaculture are not the only possible mechanisms for reducing risk, improving risk management and promoting better management practices (BMPs) in aquaculture. Some of the other possible mechanisms were outlined above. Sometimes increased insurance cover is a more expensive option for reducing exposure to risk than other available alternatives. In any case, the alternatives need to be compared and assessed. When these comparisons are done, it is likely that a combination of mechanisms (in some cases, including insurance) is desirable for risk management in aquaculture.

Conclusions

The level of investment in aquaculture is a critical factor in sustaining growth in aquaculture. Worrying signs have emerged since the Bangkok Declaration of 2000, which emphasized the importance of investment in aquaculture as a

means for its development. Recently, the global per capita availability of fish has declined, and further decline cannot be ruled out. Furthermore, there has been a recent decrease in the rate of growth of aquaculture production. While this could be because the demand for fish has fallen (because for example, red and other meat is being increasingly substituted for fish in countries such as China), this is probably not the main reason. The main reason appears to be that the development of aquaculture is being adversely and increasingly constrained by greater scarcity of vital resources because of its growth and as a result of economic growth in general. The scope for further expansion of aquaculture by its areal extension has become more limited, and its future growth is likely to become increasingly dependent on its intensification and on rises in its capital intensity. Thus, the continuing growth of aquaculture is likely to depend more than ever on adequate levels of investment in it. It will also depend on much more investment being made in R&D for the advancement of aquaculture, the application of research results and the development of infrastructure. Technological and scientific progress can be a powerful force for offsetting declining returns.

Furthermore, risk and uncertainty have been identified as a continuing and major constraint on investments in aquaculture. This restricts the rate of growth of aquaculture production. Because the relative degree of risk and uncertainty is on the whole higher in aquaculture than in other industries and the mechanisms for coping with and counteracting this risk are more restricted than in other industries, there is comparatively under-investment in aquaculture from a social point of view. Investible funds are not allocated in a manner that maximizes the aggregate value of production attainable from the resources used in the economic system. The use of resources is misallocated, given the view that human wants should be satisfied to the maximum extent possible subject to the limited availability of resources.

However, as was discussed, there are many challenges involved in developing mechanisms to rectify this misallocation problem. These challenges exacerbate collective economic scarcity. This is partly because, as was demonstrated in the case of schemes intended to increase insurance coverage in aquaculture, the implementation of mechanisms to solve the problem are themselves not costless and perfect in their operation. This paper has also demonstrated that a multitude of different methods can be used to reduce the impact of risk and uncertainty on the level of investment in aquaculture and that those economic considerations are important in deciding on which mechanism or mixture of mechanisms is appropriate in individual cases. Normally, one would expect a mixture of measures for addressing risk and uncertainty in aquaculture to be appropriate; for example, to be most economic.

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Appendix I

Notes on the economic consequences of subsidizing insurance premiums for aquaculture

Government subsidization of insurance premiums for aquaculture is a possible way of increasing the insurance cover of aquaculturists. In considering this as an approach to risk reduction experienced by aquafarmers, it is advisable to take into account several factors. These include (1) how responsive is insurance coverage likely to be to the subsidy; (2) who will be the main economic beneficiaries from the subsidy (that is, the incidence of the subsidy); and (3) how much is it likely to cost the government to provide the subsidy. Consider each of these issues in turn.

Responsiveness of insurance coverage to subsidization of provisions

In the normal case, some expansion in insurance coverage is to be expected as a result of a subsidy on insurance premiums. The extent of the expansion depends on how responsive the supply of insurance cover and the demand for insurance cover are to a change in the level of premiums. The more responsive is the supply of insurance cover to a higher premium and the greater is the demand for insurance cover to a lower premium, the greater is the increase in insurance cover to be expected as a result of subsidizing insurance premiums, other things held constant.

However, if either the demand for insurance or the supply of insurance (or both) exhibit little response to an alteration in premiums, the subsidy will not be very effective in expanding insurance coverage. In the extreme cases, where the demand for insurance is perfectly inelastic or the supply of coverage is perfectly inelastic, there is no increase in insurance cover as a result of a subsidy.

Thus, in order to know how effective subsidization of insurance premiums for aquaculture (one strategy for implementing hybrid insurance schemes), it is necessary to have empirical evidence on the slope of the supply and demand curves for insurance cover in aquaculture. It is possible that the demand for insurance cover by small-scale aquafarmers is relatively inelastic.

The incidence or income distribution effects of a subsidy for insurance cover

It is unlikely that aquafarmers would have their premiums reduced by the full amount of any government subsidy paid on premiums. If the supply and demand curves for insurance cover have normal slopes, the premium to be paid by aquafarmers for coverage will fall by less than the subsidy on premiums and a portion of the subsidy will be appropriated by insurers. The division of the subsidy (the incidence of the subsidy) between aquafarmers and insurers depends on the relative responsiveness of the supply of and demand for insurance cover. For instance, if the demand for insurance cover is less responsive to a reduction

in the insurance premium than is the supply of cover, the major portion of the subsidy will be obtained by aquafarmers.

The Cost to governments of subsidizing insurance premiums

Suppose that a government, in order to encourage aquafarmers to insure, pays a fixed percentage of their insurance premiums. Then, other things being held constant, the total cost to the government of this subsidy is larger the more responsive is the demand for aquaculture insurance to a reduction in premiums. Much depends on how a government intends to budget for the payment of its subsidy. If a fixed budget is available for the payment of the subsidy, a larger increase in insurance coverage will be possible if the insurance market is very responsive to a change in premiums than if it is not. In the former case, a smaller amount of subsidy needs to be provided on each policy than in the latter case to bring about the same level of expansion in insurance coverage.

Concluding comments

Careful consideration of supply and demand relationships in the relevant insurance market is needed to determine the consequences of hybrid insurance schemes for an expansion in insurance coverage, the distribution of subsidy payments between insurers and the insured and the public finance consequences of these schemes. Of course, apart from the actual costs of the subsidy to be paid by a government for subsidizing insurance cover, it will also have some agency or administrative costs in managing a hybrid insurance scheme. The higher are these costs, the less attractive is this policy from a social point of view.



Promoting responsible use and conservation of aquatic biodiversity for sustainable aquaculture development

Expert Panel Review 3.1

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Abstract

The world's wealth of aquatic biodiversity at the gene, species and ecosystem levels provides great potential for the aquaculture sector to enhance its contribution to food security and meet future challenges in feeding a growing human population. To realize and explore this potential, issues of access and use of aquatic genetic resources for aquaculture need to be considered. A global approach to responsible use and conservation, effective policies and plans, better information including characterization of aquatic genetic resources at different levels, and wider use of genetic applications in aquaculture are

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identified as some of the important elements needed towards an improved management of aquatic genetic resources for aquaculture, and all of these issues are dealt with in this review.

KEY WORDS: *Biodiversity, Conservation, Genetics, Sustainable aquaculture.*

Introduction

Aquaculture, the farming of fish, molluscs, crustaceans and aquatic plants (FAO, 1995) now provides more than half the total world production, traditionally supplied by wild fisheries (FAO, 2009a). It provides 15 percent of the animal protein eaten by humans, sources of key micronutrients and oils needed for healthy development, and is particularly important for human nutrition in poorer, subsistence communities (FAO, 2008). The projected increase in the world's human population is thought to require an increase in food production of 1.5–2.0 times the current production by 2050 (FAO, 2009b). Given the static or declining return from wild fisheries, the increasing demand for seafood can only be met by increasing aquaculture output (FAO, 2009a).

A doubling of aquaculture production will need to replicate agriculture development in far less time than it took to domesticate terrestrial species, in circumstances where the sites for food production are limited and which demand approaches that take account of the risk to natural biodiversity. Rapid growth of aquaculture over the last 20 years, and optimism that rapid domestication can and is being achieved in aquatic species (Duarte, Marbá and Holmer, 2007) is countered by evidence of slow penetration of genetic improvement programmes in aquaculture production (Hulata, 2001; Gjedrem, 2010). Understanding the constraints to domestication will be critical for planning effective strategies to increase sustainable production of aquatic species. This paper summarizes the history and current use of aquaculture genetic resources, identifies similarities and differences with agriculture development, and discusses the issues that will need to be addressed in promoting the responsible use and conservation of aquatic biodiversity for sustainable aquaculture development.

Biological constraints to domestication of terrestrial and aquatic species

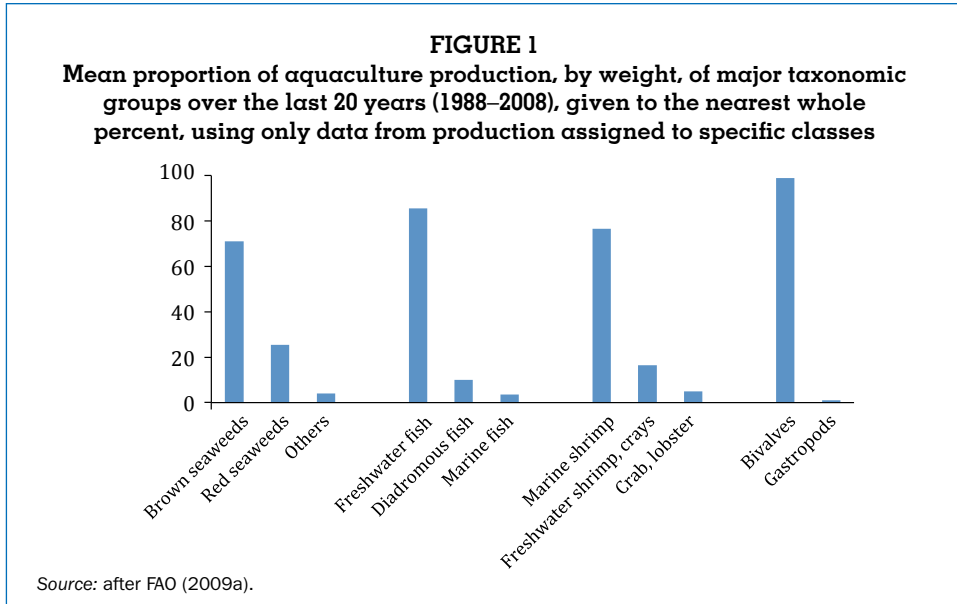
The domestication of most aquaculture species occurred in the last 100 years (Duarte, Marbá & Holmer, 2007). In contrast, about 90 percent of land animals and plants currently farmed were domesticated more than 5 000 years ago. Duarte, Marbá and Holmer (2007) suggested that species are rapidly domesticated in aquaculture because of the ease with which they can be reproduced and that, on average, about a decade of research was required in order to domesticate an aquatic species. The recency of domestication of most aquatic species is not disputed, but Bilio (2007a) has argued that Duarte,

Marbá and Holmer (2007) and others (e.g. Liao and Huang, 2000) overestimate the number of domesticated aquatic species by including those reproduced in culture from only wild-derived parents. Bilio (2007a) suggested that a criterion for domestication should be reproduction from parents raised entirely under culture for at least three consecutive generations. The issue is not one of dry definition. It is important for realistically assessing the speed with which farmed species can be improved by selective breeding. Other reviews have suggested that production from domesticated and selectively bred stocks has been limited (Hulata, 2001; Dunham *et al.*, 2001; Gjedrem, 2010). It is important to recognize that Bilio's (2007a) definition is also arbitrary, and that in any case, the few years of reproduction under culture in aquatic species is not comparable to the thousands of years experienced by terrestrial domesticated species.

Patterns of production and number of species farmed

Few species have the characteristics that make them exceptional organisms for food production (Diamond, 1997, 2002). In agriculture, those species were chosen not just because they were useful, but because they could be domesticated easily. In total, of the 200 000 wild species of higher plants known worldwide, only about 100 have become major domesticated crops, and only five account for more than 90 percent of crop production (Diamond, 2002). Similarly, only 14 out of the 148 species of large herbivores have been domesticated worldwide and five animal species are responsible for more than 90 percent of agricultural production – cattle, sheep, pigs, goats and chickens (FAO, 2007). This is despite many more species within these groups, and thousands of species in total, being accessed regularly by hunters and gatherers (Diamond, 2002). Similar constraints appear to apply to aquaculture, with only 29 species (16 finfish, 7 molluscs, 4 crustaceans and 2 seaweeds) responsible for 90 percent of production (Tables 1–5 – see end of this manuscript) although there are 31 000 finfish, 47 000 crustacean, 85 000 molluscan and 13 000 seaweed species described worldwide (World Conservation Union, 2010).

The pattern of aquaculture production for the last 20 years has been remarkably consistent and is dominated by finfish (around 50 percent) followed by plants and molluscs (each around 20–25 percent) and crustaceans (2–9 percent) (FAO, 2009a). Only 15 species have contributed to the top ten producers in that time (see Garibaldi, 1996; De Silva, 2001). Freshwater species dominate finfish production, brown and red algae, bivalves and marine shrimp dominate plant, mollusc and crustacean production, respectively (Figure 1). Bivalves filter feed naturally produced plankton from the medium and require relatively simple husbandry. Although there are some gastropods, the need for these to access considerable surface areas to graze has restricted farming to high-value species (e.g. abalone). Coastal macroalgae (seaweeds) with rapid growth are the principal plant species farmed for human consumption (McHugh, 2003). Species with long larval lives (>2–3 weeks) are not economic to farm even if their life cycles can be closed, and so shrimp and crab larvae are produced



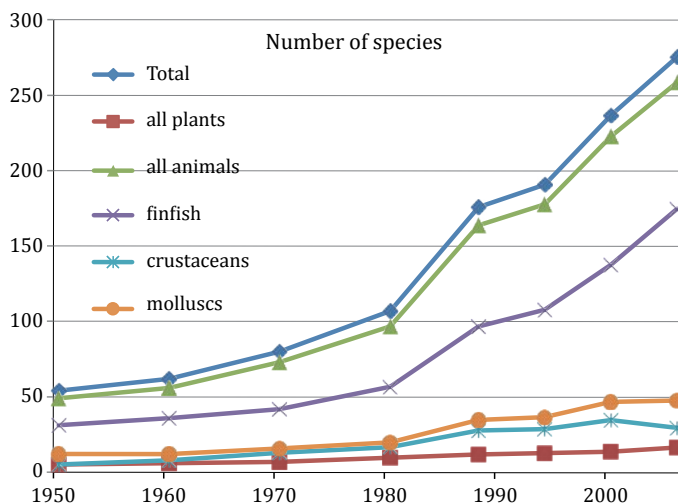
in hatcheries, but spiny lobsters are not. Species with larval stages that are difficult to feed or where aggression or cannibalism is high (e.g. in larvae or juvenile growout) are also not farmed, and these aspects of biology explain why few crabs, crayfish, lobsters and marine finfish are farmed.

Estimates of the total number of aquatic species now farmed range from 336 (Bartley *et al.*, 2009) to more than 430 (Duarte, Marbá & Holmer, 2007). Although records vary in quality (see Garibaldi, 1996), it is clear that the number of species in culture has increased at least five or six-fold from the 1950s to 339 in 2008 (Figure 2). Ninety nine percent of production in each of the major groups over the last ten years is achieved by 20–30 percent of the species farmed, but 80 percent is achieved by only 6–10 percent of farmed species, that is by 44 out of 227 finfish, 19 out of 77 molluscs, 11 out of 35 crustaceans and 2 out of 20 seaweeds (Tables 1–5).

The application of genetic improvement technologies

Humans had no planned foresight for developing agriculture and would simply have interacted with the species in their environment. Stocks were modified over several thousand years by farmers retaining only those individuals that displayed preferred features such as greater docility, milk yield or grain size, and that survived in culture conditions (Ladizinsky, 1998; Zohary and Hopf, 2000). Later, understanding of the nature of inheritance and the interaction among characters allowed the targeted and rapid improvement of many agriculture species in the last 50–100 years. Equivalent or greater gains than those attained by thousands of years of general domestication were achieved in decades.

FIGURE 2
Number of aquatic species cultured in each of the major taxonomic groupings for selected years between 1950 and 2006, where production was recorded for FAO statistics in that year



Source: Fishstat Plus (FAO, 2010b).

Given this experience with terrestrial agriculture, the advantage of utilizing genetic approaches to speed the domestication and improvement of aquaculture species was considered from the beginning of the industrial development of aquaculture. The status has been reviewed by several authors in the intervening period (e.g. Benzie, 1998, 2009, 2010; Dunham *et al.*, 2001; Hulata, 2001; Wikfors and Ohno, 2001; Penman, 2005; Gjedrem, 2005, 2010; Mair, 2007; Bilio, 2007a, b, 2008a, b; De Santis and Jerry 2007; Canario *et al.*, 2008; Bartley *et al.*, 2009; Hulata and Ron, 2009; Lo Presti, Lisa and Di Stasio, 2009; Neira, 2010; Rye, Gjerde and Gjedrem, 2010) and indicates that the speed of application of these methods is variable among groups and has yet to impact production as widely as had been hoped.

In order to provide an up-to-date assessment of the current status of the application of genetic improvement technologies to aquaculture production, a series of searches of the scientific literature using major digital science databases subsequent to the times of publication of a number of major reviews in the last decade or so (see citations in previous paragraph) were undertaken. Attention is focussed on the species responsible for the major proportion of production for the ten years from 1999–2008, using only production that could be traced to a named taxon. All entries for unidentified classes (most designated “nei” in the FAO data) were excluded. The proportion of species in each group for which particular data or technologies exist are summarized in Table 1, and detailed results are tabulated separately for finfish (Table 2), molluscs (Table 3), crustaceans (Table 4) and seaweeds (Table 5).

TABLE 1

The proportion (percent) of finfish, molluscan, crustacean and seaweed species for which there is information on wild stock structure; domestication (D), genetic selection programmes (Gl), genetic parameter estimates (GP); hybridization (C – crossbreeding of strains; H – interspecies hybridization); molecular resources including EST numbers (Est), parentage tracking (PT), quantitative trait locus markers (Qtl), large insert libraries such as BACs or FOSMIDs (LIL), and microarrays (Mar); genetic maps and other genetic methodologies such as cryopreservation (Cr), sex manipulation (SM), gynogenesis (G), androgenesis (A), clonal lines (CL), ploidy manipulation (Pl), and direct gene transfer (GMO). Tot represents the proportion of species for which any of these technologies exist for molecular and map resources or for other genetic technologies. The information is abstracted from Tables 2–5 which give information for each species of each of the major taxonomic groupings. Production data are from *Fishstat Plus* (FAO, 2010b).

	Wild stock structure	Genetic election		Hybrids		Molecular resources			Genetic maps	Other genetic technologies													
		D,	Gl,	GP	C	H	Est,	PT,		Qtl,	LIL,	Mar	Tot	Cr,	SM,	G,	A,	CL,	Pl,	GMO,	Tot		
Finfish																							
99 % of production (44 species)	89	66	32	39	18	34	27	18	20	23	16	39	50	23	20	27	9	9	41	32	52		
Others (<1% of production) (183 species)	67	34	4	9	2	9	10	9	2	1	5	4	21	9	6	4	7	1	12	5	25		
Molluscs																							
99 % of production (19 species)	100	42	21	26	5	0	32	16	11	0	11	21	42	21	0	0	0	0	2	37	5	42	
Others (<1% of production) (58 species)	79	38	24	12	4	8	3	3	5	2	0	7	12	0	0	0	0	0	22	0	22	0	22
Crustaceans																							
99 % of production (11 species)	100	73	36	55	9	0	45	45	18	36	0	36	46	45	9	0	0	0	18	36	64	64	
Others (<1% of production) (24 species)	71	4	8	13	0	0	4	4	0	0	0	0	4	4	4	0	0	0	4	0	13	13	
Seaweeds																							
99 % of production (2 species)	100	100	100	100	100	100	0	100	0	0	0	0	100	0	0	0	0	0	100	0	100	100	100
Others (<1% of production) (20 species)	?											0											0

TABLE 2

Finfish species responsible for 99 percent of aquaculture production traceable to individual species from 1999–2008, ranked in order of average production over that period (*Fishstat Plus*, FAO, 2010b). The tally for 80, 90, 95 and 99 percent of production is given in the species ID column to the right of the species name. The total number of species recorded includes those in the FAO records and others recorded from the literature as being farmed, but which are not all recorded separately in the FAO statistics. The table summarizes whether there is information on a) wild stock structure [+ yes, (+) very limited, - no]; b) domestication (D), with time in years given for the longest programme known for domestication (Dyr) [∞ from Billo (2007a,b) refers to many generations, probably >30] and genetic improvement by selection (Glyr), and whether there are genetic parameter estimates (h – heritability, gc – genetic correlations, r – response to selection, gxe – genotype environment interactions); c) hybridization (C – crossbreeding of strains; H – interspecies hybridization); d) molecular markers EST numbers, parentage tracking (PT) quantitative trait locus markers (Qtl), large insert libraries (Lil) such as BACs or FOSMIDs, or whether a microarray (Mar) of genes exists for that species; e) genetic maps with the type of marker (A – AFLP, M – microsatellite, S – SNP, o – other: capitals for major component, lower case for small contribution) noted, and the largest number of markers mapped on any one map for that species; f) other genetic methodologies used: Cr – cryopreservation, SM – sex manipulation, G – gynogenesis, A – androgenesis, P – ploidy manipulation, CL – clonal lines, GMO – direct gene transfer. * – indicates use in industry, b – use in breeding programmes, e – experimental scale operation, t – commercial trials. The number of species for which data or a given technology exists is given in the row named TOTAL (number of taxa listed given in parentheses), and below this a summary of data for the additional finfish species with lower production values, for which space limitations prevented inclusion of their individual data in the Table. The number in bold face at the right of the column for other technologies indicates the proportion of species for which any of these technologies exist. Summary references for the sources are given in a separate list at the end of the paper.

Species	Wild stock structure	Genetic selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
Silver carp, <i>Hypophthalmichthys molitrix</i>	+	D*, ∞ , >20, h	C H e	Est, PT, Qtl, Lil, Mar -, PT, -, -	Type, No. AM 483	Cr, SM, G, A, CL, P, GMO Cr, SMe, Ge,	1,2,5,14,16,18,50
Grass carp, <i>Ctenopharyngodon idella</i>	+	D*, ∞ , -, h	e	10^2 ; -, -, -	Ms 279	Cr, SMe, Ge, Pb*, GMOe	1,2,4,6,8,13,17,18
Common carp, <i>Cyprinus carpio</i>	+	D*, ∞ , >40, h,r,gxe	b* - e	10^4 ; -, -, BAC, M	MA 719	Cr, SM*, Ge, A*, CL, Pe, GMOet	1,2,4,6,7,8,9,12,19,20,21,22,23,26
Bighead carp, <i>Hypophthalmichthys nobilis</i>	+	D*, ∞ , -, -	e	-	Am 153	Cre, Pe	1,2,5,6,15,18
Crucian carp, <i>Carrasius carassius</i>	(+)	D*, -, -, -	e e	-	-	Cre, Gb, A, CL, Pb*, GMOe	1,7,18,27
Nile tilapia, <i>Oreochromis niloticus</i>	+	D*, ∞ , >20, h,r,gxe	b* * e	10^5 ; -, <10, BAC, -	M 525	SMb*, Ge, - CL, Pe, GMOe,	1,2,4,5,6,7,11,31
Atlantic salmon, <i>Salmo salar</i>	+	D*, ∞ , >39, h,r,gxe	e	10^5 ; -, 10-20, BAC, M	A, MS 527	SMb*, Gb, Pb*, GMOet	1,2,3,4,5,6,7,8,10,47,48,51
Catla, <i>Catla catla</i>	+	D, ∞ , ? , -	-	-	-	Pe, GMOe	1,2,6,18,28,29
Roho labao, <i>Labao rohita</i>	+	D, 6+, ? , h	e -	-	-	GMOe	1,2,6,7,8,18,30
Milkfish, <i>Chanos chanos</i> 80	+	-	-	-	-	-	1,40,41
Rainbow trout, <i>Oncorhynchus mykiss</i>	+	D*, ∞ , >39, h,r,gxe	b* b	10^5 ; -, >20, BAC, M	AMS0 1359	Cre, SMb*, Gb*, Ab, CL, Pb*, GMOe,	1,2,4,5,6,7,8,10,49,51

TABLE 2 (Continued)

Species	Wild stock structure	Genetic selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
		D, Dyr, Glycer, GP	C H	Est, PT, QT, LIL, Mar	Type, No.	Cr, SM, G, A, CL, P, GMO	
Blunt snout bream, <i>Megalobrama amblycephala</i>	(+)	D*, >30, >25, r	-	-	-	Pe, GMOe	1, 6, 18, 32, 57
Mrigal carp, <i>Cirrhinus cirrhosus</i>	+	D, ∞, ?, r, -	-	-	-	GMOe	1, 2, 18, 24, 25
Channel catfish, <i>Ictalurus punctatus</i>	+	D*, ∞, 19, h, r	b* b*	10 ⁵ PT, -, BAC, M	A, Ms 331	Pe, GMOe	1, 2, 4, 5, 6, 8, 33, 34, 35, 36, 37
Black carp, <i>Mylopharyngodon piceus</i>	+	-	-	-	-	Ge	18
Japanese eel, <i>Anguilla japonica</i>	+	-	-	10 ² , ;, ;, ;, -	-	-	4, 38, 39
Amur catfish, <i>Parasilurus asotus</i>	+	-	-	-	-	-	58
Flathead grey mullet, <i>Mugil cephalus</i>	+	-	-	-	-	-	42, 43, 44
Japanese amberjack, <i>Seriola quinqueradiata</i>	-	-	-	10 ³ , ;, ;, ;, -	M 175	-	59, 60, 61
Snakehead, <i>Channa argus argus</i>	(+)	-	-	-	-	-	62
Mandarin fish, <i>Siniperca chuatsi</i>	+	-	-	-	-	-	45, 46
Coho salmon, <i>Oncorhynchus kisutch</i>	+	D*, ∞, r, h, gc, r	e	-, -, <10, -, -	AM 281	SM*, Pe, GMOe	1, 2, 5, 6, 7, 8, 10, 51, 63, 64, 65, 66
Githead seabream, <i>Sparus aurata</i>	+	D*, >5, 8, h, r, gc, c	b* -	10 ³ PT, <10, BAC, M	M 204	Pe	1, 2, 4, 5, 6, 52, 53, 54, 55, 56
Asian swamp eel, <i>Monopterus albus</i>	+	-	-	-, -, -, BAC, -	-	-	67, 68, 69
Largemouth black bass, <i>Micropterus salmoides</i>	+	D, ?, 6, r	-	-	-	-	70, 71
Goldlined seabream, <i>Rhabdosargus sarba</i>	-	D, ?, r, -	-	-	-	GMOe	1.8
Pond loach, <i>Misgurnus anguillicaudatus</i>	+	-	e	-	M 153	Cr, Ge, Ae, NT, Pb, GMOe	1, 6, 8, 72, 75, 76
Mud carp, <i>Cirrhinus molitorella</i>	(+)	-	-	-	-	-	18, 77
European seabass, <i>Dicentrarchus labrax</i>	+	D*, 20, 5, h, gc, gc	-	10 ⁴ PT, 10-20, BAC, M	MAs 368	Pe	1, 4, 5, 6, 78, 79, 80, 81,

TABLE 2 (Continued)

Species	Wild stock structure	Genetic selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
		D, Dyr, Glyr, GP	C H	Est, PT, Qtl, LIL, Mar	Type, No.	Cr, SM, G, A, CL, P, GMO	
<i>Pacu, Piaractus mesopotamicus</i>	-	D, ∞, r, *	- *	- , PT, -	-	-	2,82
Japanese seabass, <i>Lateolabrax japonicus</i>	+	D*, ∞, r, *	-	-	-	-	3,83
Asian redtail catfish, <i>Hemibagrus nemurus</i>	+	-	-	-	-	-	84,85
Mozambique tilapia, <i>Oreochromis mossambicus</i>	+	D, ?, ?	- *	- , - , <10, - , -	-	-	86,87,88
Bastard halibut, <i>Parralichthys olivaceus</i>	+	D*, >5, - , h, gc	-	10 ³ , PT, 1, BAC, M	AM 463	SM*, G*, P* MAS	1,3, 4, 5, 6, 89, 95, 96
Large yellow croaker, <i>Larimichthys crocea</i>	+	D*, ∞, r, *	-	-	Am 188	Ge, Pe	3, 90, 91, 92, 93
Snakeskin gourami, <i>Trichogaster pectoralis</i>	+	-	-	-	-	-	94
Chachama, <i>Colossoma macropomum</i>	+	D, >30, r, *	- *	-	-	-	2,100,101
Barramundi, <i>Lates calcarifer</i>	+	D, >3, r, h, gc	-	10 ³ , PT, 10-20, BAC, -	Mo 240	Pe	2,3,4,97,98,99,102
Red drum, <i>Sciaenops ocellatus</i>	+	D, ∞, r, *	-	- , PT, -	M 237	-	2,3,103,104,105,106,107
Giant gourami, <i>Osphronemus goramy</i>	-	-	-	-	-	-	-
North African catfish, <i>Clarias gariepinus</i>	+	D, ∞, >4, -	e b*	- , PT, -	-	Pe	1,2,6,7,73,74
Blackhead seabream, Korean/Schlegel's black rockfish, <i>Acanthopagrus schlegelii schlegelii</i>	+	D*, ∞, r, *	-	-	-	-	3,108,109
Striped catfish, <i>Pangasianodon hypophthalmus</i>	+	D, >30, >10, h, gc, r	- *	-	-	-	2,110,111
Bonnylip barb, <i>Osteochilus vittatus</i> 99	-	-	-	-	-	-	18
TOTAL (44 species)	39	D 29 GI 14 GP 17	8, 15	12, 8, 9, 10, 7	17	10, 9, 12, 4, 4, 18, 14 23	
Others (<1% of production) (183 species)	123	D 62 GI 8 GP 16	3, 17	19, 17, 3, 2, 9	7	17, 10, 8, 12, 2, 22 9 45	

A higher proportion of species contributing to the top 99 percent of production were domesticated according to Bilio's (2007a) criteria (42–73 percent) compared with those contributing less than 1 percent of production (4–38 percent) in each taxonomic group (Table 1). This pattern is repeated more strongly for all other classes of technology. A higher proportion of top producing species have molecular resources or other genetic technologies developed compared with low-production species. There is also a trend for greater development of sophisticated technologies in species produced in developed rather than developing countries; for example – silver carp (*Hypophthalmichthys molitrix*) (1st ranking), grass carp (*Ctenopharyngodon idella*) (2nd) and bighead carp (*H. nobilis*) (4th) have much fewer molecular resources and other genetic technologies applied to them compared to common carp (*Cyprinus carpio*) (3rd), Nile tilapia (*Oreochromis niloticus*) (6th), Atlantic salmon (*Salmo salar*) (7th), rainbow trout (*Oncorhynchus mykiss*) (11th), channel catfish (*Ictalurus punctatus*) (14th), gilthead seabream (*Sparus aurata*) (23rd) or European seabass (*Dicentrarchus labrax*) (29th) (Table 1). A greater proportion of high-production finfish and crustacean species have been subjected to genetic improvement and/or genetic parameter estimation (32–55 percent), molecular resource (46–50 percent) or other genetic technology development (52–64 percent) than molluscs, which have respectively 21–26 percent, 42 percent and 42 percent of species in each of these categories. Each of the technologies is now considered in more detail.

Quantitative genetics and selective breeding

Selective breeding can only be achieved in populations in which the life cycle has been closed and the species reliably and routinely reproduced each generation from parents reared in culture (i.e. domesticated). Only about half of the high-production species in each of finfish, molluscan and crustacean groups recorded as domesticated is subject to targeted genetic improvement today (Table 1). Genetic parameters, which provide information needed to design efficient selection programmes, have been estimated for slightly more because these can be estimated using measures over one generation, and are often done to assess the potential utility of applying selection to a species.

Genetic parameter estimation

The genetic parameter estimates available for seaweeds (Chapman, 1974; Patwary and van der Meer, 1992), finfish (Dunham *et al.*, 2001; Carlson and Seamons, 2008) molluscs (Boudry, 2009) and crustaceans (Jerry, Purvis and Piper, 2002; Wong and McAndrew, 1994; Thanh *et al.*, 2009; Benzie, 2010) have been summarized by those authors. In general, heritabilities show values of around 0.3–0.5 for characters related to growth, suggesting they would respond well to selection, as have a range of other characters related to reproduction and resistance to some diseases. Low heritabilities (<0.1 to 0) for responses to other disease agents suggest that attempts to breed resistant

strains for these are unlikely to be economic. Genetic correlations show a variety of relationships but indicate strong correlation of various measures of growth, and often divergent correlations between these and reproductive or disease tolerance traits, and between larval and postlarval growth in molluscs (Boudry, 2009). These results indicate care is required in the design of breeding programmes so that selection for one advantageous character does not result in selection against another economically important one.

Aquatic species tend to have higher genetic variance (20–35 percent) than agricultural ones (10 percent or less), and higher fecundity which, in general, allows for potentially higher selection intensity (Dunham *et al.*, 2001). Good response to selection has been observed with improvements in growth of 10–20 percent per generation recorded for several finfish (including salmon, carp and tilapia) and shrimp, although longer-term responses in many programmes average around 5 percent per year for most finfish, shrimp and molluscs. The number of cases in which the results of selection have been estimated to be similar in different environments (GxE or genotype by environment interaction) are few. However, lack of GxE effects for Atlantic salmon, Nile tilapia or Sydney rock oyster (*Saccostrea glomerata*) allowed the development of single improved strains that provided better production in a variety of environments.

Genetic improvement through selective breeding

Despite the generally positive results from estimation of genetic parameters, there are still relatively few breeding programmes of significant production scale. In seaweeds, there has been genetic improvement and successful novel strain development only in *Laminaria* (Wu and Lin, 1987), *Porphyra* (Miura, 1976; Ohme, Kunifuji and Miura, 1986; Shin and Miura, 1990) and *Undaria* (Chaoyuan and Guangheng, 1987). Significant improvement of plant quality and yield, disease resistance and stress tolerance of *Laminaria* varieties has been achieved, with more than ten varieties used in cultivation (Zhang *et al.*, 2007). Improvements in some strains include 8–40 percent more biomass and/or some 20–50 percent more iodine than original stocks (Wu and Lin, 1987).

Despite some of the largest production by individual species being from molluscs, few have been domesticated. Boudry (2009) lists only three subject to significant genetic improvement programmes: Giant cupped oyster (*Crassostrea gigas*), Sydney rock oyster and New Zealand green mussel (*Perna canaliculus*), and only the smaller programme for American cupped oyster (*C. virginica*) is recorded in addition in Table 3 for high-production species. Programmes have been started for the greenlip abalone (*Haliotis laevis*) and the Peruvian calico scallop (*Argopecten purpuratus*). Among crustaceans, large-scale genetic improvement programmes exist only for marine prawns (Benzie, 2009), although some small-scale programmes exist for freshwater crayfish (Wickens and Lee, 2002) and recently for two freshwater prawn (*Macrobrachium*) species (New, 2005; Thanh *et al.*, 2009, 2010). There are two or three major programmes

TABLE 3

Molluscan species responsible for 99 percent of aquaculture production traceable to individual species from 1999–2008, ranked in order of average production over that period (*Fishstat Plus*; FAO, 2010b). The tally for 80, 90, 95 and 99 percent of production is given in the species ID column to the right of the species name. The total number of species recorded includes those in the FAO records and others recorded from the literature as being farmed, but which are not all recorded separately in the FAO statistics. Details of the technologies and column headings are given in the legend to Table 2 for finfish. Summary references for the sources are given in a separate list at the end of the paper

Species	Wild stock structure	Genetic selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
Manila clam, <i>Ruditapes philippinarum</i>	+	D, ∞, ∞, ∞, -	C H	Est, PT, Qt, LIL, Mar	Type, No.	Cr, SM, G, A, CL, P, GMO	1,3,5,7,18,19
Giant cupped oyster, <i>Crassostrea gigas</i>	+	D*, ∞, ∞, >30, h, gc, r, gxe	b*	10 ⁴ , PT, <10, -, M	A, M 119	Cr, Pb*	1,2,3,4,5,6,7,9,10,11,12,23,24
Constricted tagelus, <i>Sihonovacula constricta</i>	+	D, ∞, ∞, ∞, -	-	10 ³ , ∞, ∞, ∞, ∞, -	-	-	3,15,29
Granular ark, <i>Tegillarca granosa</i>	+	D, ∞, ∞, ∞, -	-	-	-	-	3,30,31
Asian brown mussel, <i>Perna viridis</i>	+	-	-	-	-	-	13,14
Large weathered scallop, <i>Patinopecten yessoensis</i> 80	+	-	-	10 ³ , PTe, ∞, ∞, ∞, -	Am 166	Pe	1,3,5,16,17,20,21,22,27,28
Blue mussel, <i>Mytilus edulis</i>	+	D, ∞, 2e, -	-	10 ⁴ , ∞, ∞, ∞, ∞, -	A 198	Pe	1,2,3,4,5,7,11,25,26
Bay mussel, <i>Mytilus galloprovincialis</i>	+	∞, 3, ∞, ∞, -	-	10 ⁴ , ∞, ∞, -	-	Pe	2,32,33,38,39
New Zealand green mussel, <i>Perna canaliculus</i> 90	+	D*, 8, 8, -	-	-PT, ∞, ∞, -	-	Cre	4,50,56
Chilean mussel, <i>Mytilus chilensis</i>	+	∞, ∞, h, gxe	-	-	-	-	4, 48,49
American cupped oyster, <i>Crassostrea virginica</i>	+	D*, >10, >10, h, gc, r, gxe	-	10 ³ , ∞, 10, 20, -, M	Am 114	Pe, GMOe	2, 4, 7, 8, 23,36,37,41,55
Swan mussel, <i>Anodonta cygnea</i>	+	-	-	-	-	-	51
Chinese mystery snail, <i>Cipangopaludina chinensis</i> 95	+	-	-	-	-	-	47
Far eastern mussel, <i>Mytilus coruscus</i>	+	-	-	-	-	-	4,46
Japanese hard clam, <i>Mercenaria mercenaria</i>	+	-	-	-	-	-	45
Northern quahog hard clam, <i>Mercenaria mercenaria</i>	+	D*, >10, ∞, h, gc, gxe	-	-	-	Pe	2, 7, 34, 44, 52,53,54
Peruvian calico scallop, <i>Argopecten purpuratus</i>	+	∞, ∞, ∞, h	-	-	-	-	35,43
Asian clam, <i>Corbicula fluminea</i>	+	-	-	-	-	-	42
Philippine cupped oyster, <i>Crassostrea iredalei</i> 99	(+)	-	-	-	-	-	40
TOTAL (19 species)	19	D 8, Gl 4, GP 5	1, 0	6, 3, 2, 0, 2	4	4,	71 8
Others (<1% of production) (58 species)	46	D 22, Gl 14, GP 7	1, 2	2, 2, 3, 1, 0	4	0, (CL 1), 13 0	13

established for whiteleg shrimp (*Litopenaeus vannamei*) and a smaller number for giant tiger prawn (*Penaeus monodon*), but many regional programmes have utilized stock from the major programmes (Benzie, 2009). They have achieved strains improved for growth and for resistance to Taura syndrome virus (TSV).

Only 22 species of finfish out of 91 recorded as domesticated, and only 14 of the high-production species are subject to selective improvement (Table 2). These programmes have focused on carps, salmonids, tilapia, channel catfish, striped catfish (*Pangasianodon hypophthalmus*), gilthead seabream and European seabass. The ancient and separate domestication of regional varieties of common carp (European, Asian and Far Eastern), and their extensive regional trade has produced more than 60 recognized breeds in China, including 20 alien varieties or hybrid lines, and 80 strains (60 national and 25 foreign) in central and eastern Europe (Flajšhans and Hulata, 2007; Jeney and Jian, 2009). Many of these arose from long-term domestication, but a number of programmes have now been developed for targeted genetic improvement through hybridization and selection. The other major carp producing species (labeo roho (*Labeo rohita*), silver carp, grass carp, bighead carp and Crucian carp (*Carassius carassius*)) were also domesticated in the distant past, but targeted genetic improvement established only in the last 10–20 years (Bilio, 2007a, b). Bilio does not mention commercial genetic improvement programmes but does mention establishment of pedigrees for some of these species in Europe. There are a few references for heritability (h^2) estimation and/or selective breeding from China (Li, Peng and Zhao, 1987; Gheyas *et al.*, 2009) and Viet Nam (Penman, 2005) for silver carp.

There are captive breeding programs for several stocks of each of rainbow trout, chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*), and for some 32 natural stocks of Atlantic salmon (*Salmo salar*) aimed at restocking and conservation. Genetic improvement programmes aimed at aquaculture production of Atlantic salmon began in Norway in 1971, and there are now 14 different selective breeding programmes for this species, the latest started in Australia in 2004. There are four for rainbow trout, the first started in Norway in 1971 and the latest in Chile in 2000, two for arctic char (*Salvelinus alpinus alpinus*) begun in 1986 and 1992, and one for chinook salmon (Solar, 2009). In general, these have demonstrated considerable response to selection for increased growth rates of five percent per generation in rainbow trout, Atlantic salmon, channel catfish, tilapia and other species summarized in Dunham *et al.* (2001) and Gjedrem (2005); and to resistance to some diseases, such as furunculosis in brook trout (*Salvelinus fontinalis*) (by 67 percent), infectious pancreatic necrosis virus (IPNV) in rainbow trout (by 92 percent), and for other key production traits.

Irrespective of the time for which a species has been domesticated, the breeding programmes designed for food production from aquaculture are all less than 40

years old: five of the 14 high-production finfish and one of the three molluscs are less than 10 years old, 7 finfish, 1 mollusc and 3 shrimp are 10–20 years old, and 4 finfish, 1 mollusc and 1 shrimp more than 20 years old.

Crossbreeding and hybridization

Hybrids whose growth rate is greater than either of the parent strains (i.e. they display heterosis), which have useful combinations of characters not found in the parents, which are sterile or are composed largely of only one sex are valuable for production. Different breeding regimes to those designed to increase performance by selecting each generation within a line are needed for these. Bartley, Rana and Immink (2001) review the use of hybrids in aquaculture and some detail of both intra- and inter-specific crosses is summarized in Dunham *et al.* (2001).

Crossbreeding strains of the same species is rarely used in molluscs, with records of its use only for *C. gigas* and one low-production species (Table 3), and not at all in crustaceans (Table 4), although some strain testing has been carried out for *Macrobrachium* (Thahn *et al.*, 2010). It is reported for eight of the high-production finfish species (Table 2). Most interspecific crosses result in few or no offspring, which are often inviable or poorly performing. This is the case in all crustacean (Benzie, 2009) and nearly all molluscan (Boudry, 2009) hybrids which have been tested. Although most finfish crosses fail, more have proved successful (Dunham *et al.*, 2001). Therefore, no use of interspecies hybrids is reported for the high-production molluscs and crustaceans, while hybridization at an experimental level at least is reported for 34 percent of high-production finfish (Table 2).

Large increases in growth rate of crossbreeds of channel catfish (55 percent improvement), rainbow trout (22 percent) and a few common carp strains (3 of 140 tested) have been reported (Dunham *et al.*, 2001). Only five-high production species crossbreeds contribute significantly to production (i.e. common carp, Nile tilapia, rainbow trout, channel catfish and gilthead seabream), but it is impossible to determine their relative contribution to production. High-production species whose interspecies hybrids have faster growth than their parental species include hybrids of channel and blue catfish (*Ictalurus furcatus*) and *Clarias* catfish hybrids. Those which are preferred for better combinations of growth rate and ratio of head to body size include crosses of common carp with labeo rohu, mrigal carp (*Cirrhinus cirrhosus*), catla (*Catla catla*) and fringed-lipped peninsula carp (*Labeo fimbriatus*) in Asia, and of chachama (*Colossoma macropomum*) and pacu (*Piaractus mesopotamicus*) in South America. Other finfish hybrids have been used to produce single-sex populations (several tilapia species for largely male progeny, and striped bass (*Morone saxatilis*)/yellow bass (*M. mississippiensis*) crosses for all-female offspring). The advantage of these crosses is the greater production of the faster-growing sex, giving better size distribution in the production populations. Sterile hybrids can have improved

TABLE 4

Crustacean species responsible for 99 percent of aquaculture production traceable to individual species from 1999–2008, ranked in order of average production over that period (*Fishstat Plus*, FAO, 2010b). The tally for 80, 90, 95 and 99 percent of production is given in the species ID column to the right of the species name. The total number of species recorded includes those in the FAO records and others recorded from the literature as being farmed, but which are not all recorded separately in the FAO statistics. Details of the technologies and column headings are given in the legend to Table 2 for finfish. Summary references for the sources are given in a separate list at the end of the paper

Species	Wild stock structure	Genetic Selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
		D, Dyr,Glyr,GP	C H	Est, PT, Qtl, LL, Mar	Type, No.	Cr, SM, G, A,CL,P, GMO	
Whiteleg shrimp, <i>Litopenaeus vannamei</i>	+	D*, ∞, >20, h,gc,r,gcxe	-	10 ⁵ , PT, <10, BAC FOS, -	A,M,S 418	Cr, GMOe	1,2,3,4,9
Giant tiger prawn, <i>Penaeus monodon</i>	+	D*, ∞, >10, h,gc,r,gcxe	-	10 ⁴ , PT, -, FOS, -, -	AMo 547	Cr, GMOe	1,2,3,4,9
Chinese mitten crab, <i>Eriocheir sinensis</i>	+	-	-	10 ⁴ PT, -, -, -, -	-	Cr,	2,5,6,7,8,13,14
Giant river prawn, <i>Macrobrachium rosenbergii</i>	+	D, >30,r, h,gc	-	-	-	-, SM	2,15,17
Oriental river prawn, <i>Macrobrachium nipponense</i>	+	-	-	-	-	-	15,16,18,19
Red swamp crawfish, <i>Procambarus clarkii</i>	+	-,r,-, h	-	-	-	GMOe	9,10,11,12,21
Fleshy prawn, <i>Fenneropenaeus chinensis</i>	+	D*, ∞,12/30,h,gc,r	-	10 ⁴ , PT, -, BAC, -	A,M 197	Cr, Pe	2,3,4
Giant mud crab, <i>Scylla serrata</i>	+	D, ∞, -	-	-	-	-	3,20
Banana prawn, <i>Fenneropenaeus merguensis</i>	+	D*, 14,?,r,-	-	-	-	-	1,2,4
Kuruma prawn, <i>Marsupenaeus japonicus</i>	+	D*, ∞, >10, h,gc,r,gcxe	-	10 ³ , PT, <10, -BAC, -	A 245	Cr, Pe, GMOe	1,2,3,4
Indian white shrimp, <i>Fenneropenaeus indicus</i>	(+)	D, 6,?, -	-	-	-	-	2,4
Number with data/technology							
TOTAL (11 species)	11	D 8, Gl 4, GP 6	0, 0	5, 5, 2, 4, 0	4	5, 1, 2,	4 7
Others (<1% of production) (24 species)	17	D 1, Gl 2, GP 3	0, 0	1, 1, 0, 0, 0	0	1, 1, 1,	0 3

growth rates by saving the energy used in gamete production, but a significant advantage in the absence of improved growth is the lack of inter-breeding with wild populations. That is one of the principal reasons for the use of hybrids of salmonid species. Inter-species hybridization of gametophytes in seaweeds has successfully provided exploited heterosis in the progeny and an elite *Laminaria* variety, 90-1, introduced to production in 1997, spread rapidly to occupy about one-third of the cultivation area in China by 2004 (Zhang *et al.*, 2007).

Case studies of structured breeding programmes

The first structured breeding programme with a goal to selectively improve fish for aquaculture production was begun on Atlantic salmon in the early 1970s, and its history is recorded by Gjedrem (2010). It is the closest to a process using agriculture experience as a guide, and it is no accident that those involved had a background in livestock breeding. Several salmonid species were considered and their performance in freshwater and seawater culture assessed, with Atlantic salmon and rainbow trout proving to have the best characteristics desired for farming. Inter-species crosses were tested for heterosis but proved difficult to produce and to have poor performance, so excluding crossbreeding as an effective approach to improvement in salmon. An extensive comparison of 100 or more strains of Atlantic salmon from different rivers showed up to a 20 percent difference in performance in culture. The inclusion of only the best-performing strains in constructing the base breeding population meant large immediate gains. Testing more than 200 families per year allowed the estimation of the heritability and genetic correlations for a number of traits of interest, and testing in different locations and different environments showed genotype by environment interaction were low, suggesting only one line would be required to provide a selectively improved fish useful in the full range of farming environments used. The programme achieved 10 percent improvement in fish growth per year, and by 1992 had provided a specific benefit to the Norwegian industry of NOK194 million, a return on investment of 15:1, and a substantial industry producing more than 130 000 tonnes per year from a start only 20 years before. Extensive transfer of these stocks worldwide, in particular to Chile, allowed the development of new industries in the southern hemisphere. From no genetically improved stocks being available in 1970, 97 percent of Atlantic salmon production in 2003 was estimated to be from genetically improved stocks.

The other successful large-scale domestication and breeding programme, for tilapia, used a similar approach most recently summarized in Eknath and Hulata (2009), Ponzoni, Nguyen and Kaw (2007), Ponzoni, Kaw and Yee (2010) and Ponzoni *et al.* (2010). International funding provided to a non-governmental organization (NGO), the International Center for Living Aquatic Resources Management (ICLARM) in 1988, allowed testing several tilapia strains in a number of different environments in the Philippines, the estimation of a number of genetic parameters and the subsequent construction of a substantial

TABLE 5

Plant species responsible for 99 percent of aquaculture production traceable to individual species from 1999–2008, ranked in order of average production over that period (*Fishstat Plus*, 2010b). The tally for 76 and 99 percent of production is given in the species ID column to the right of the species name. The total number of species recorded includes those in the FAO records and others recorded from the literature as being farmed, but which are not all recorded separately in the FAO statistics. Details of the technologies and column headings are given in the legend to Table 2 for finfish. All seaweed species listed have additionally techniques for somatic hybridization applied to them. Sources are to original work only if the basic information is not provided in major reviews, which are otherwise referenced. Summary references for the sources are given in a separate list at the end of the paper

Species	Wild stock structure	Genetic Selection	Hybrids	Molecular markers	Genetic maps	Other genetic technologies	Source
Japanese kelp, <i>Laminaria japonica</i>	+	D, Dyr, Glycer, GP D*, ∞, >40, h	C H b* b*	Est, PT, Qi, L, IL, Mar , PT, , , -	Type, No. -	Cr, SM, G, A, CL, P, GMO CL, GMOe	1, 2, 3, 1, 3, 4
Wakame, <i>Undaria pinnatifida</i>	+	D*, ∞, >30, h	b* b*	, PT, , , -	-	CL, GMOe	1, 3, 4
Number with data/technology							
TOTAL (2 species)	2	D 2, GI 2, GP 2	2, 2	0, 2, 0, 0, 0	0	2	2 2
Others (<1% of production) (18 species)	?	?	?	?	?	?	

pedigree-based selection programme. Low GxE suggested only one line would provide for production in a range of environments. The programme achieved growth improvements of 12 percent per generation, an ultimate return on investment of more than 70 percent, and a resource supporting new aquaculture developments in much of Asia, including the development of several regional selective breeding programmes. Key components of the programme included the development of distribution networks for the improved fry so that farmers could access the material. The Genetic Improvement of Farmed Tilapia (GIFT) programme demonstrated the feasibility and cost-effectiveness of genetic improvement for tropical fish by its completion in 1997. At that stage, the breeding operations were transferred to a non-profit body. However, this was ultimately uneconomic and was taken over by a private company that now supplies tilapia seed to the aquaculture industry worldwide. In addition, several independent breeding programmes starting from GIFT material are also carried out in several countries in Southeast Asia.

In contrast, many other programmes developed from the immediate need to provide more reliable supplies of seed for production systems and closed breeding populations were produced as a result. Begun with little thought for quality and genetic diversity, many of these failed through lack of sufficient capital and the deleterious consequences of unintended inbreeding. Others were able to introduce new stocks, develop sound breeding approaches and ultimately become successful. Examples are provided by several shrimp species, including *L. vannamei*, summarized in Benzie (2009). This species' development was greatly advantaged by research over two decades on several aspects of shrimp biology by the US Marine Shrimp Consortium, and led to strains improved for growth and TSV resistance. Improved broodstock were supplied internationally by the research agency involved and by United States producers, and nearly all production of *L. vannamei* worldwide now uses selectively improved stock.

Key to the continued success of all these programmes, and the molluscan ones as described by Boudry (2009), was the collaboration between government and industry, and access to adequate investment and key skills over the time needed to develop the improved stocks. Whether planned from the outset or developed as a response to challenges emerging from changing circumstances, these collaborations and interactions between various sectors, often from different countries, were required for the successful transformation of a good technical programme into an effective supply of improved stock to farmers. However, even where technical success is achieved, improved strains may have little impact if rejected by industry, as Boudry (2009) describes for oyster programmes in Europe. Even where significant investment and strong genetic skills are applied for significant periods (more than ten years as in the cod improvement programme), effective industrial production may not be achieved if aspects of husbandry technology are not efficient or market conditions not suitable.

Molecular and genomic tools

Molecular genetic, genomic and biotechnological applications for a wide range of cultured fish are reviewed in Dunham (2004), Canario *et al.* (2008), Gjedrem and Baranski (2009) and Cerdà, Douglas and Reith (2010); reviews of genomics in molluscs are given by Saavedra and Brachère (2006), and Gestal *et al.* (2008) and for aquaculture generally by Kocher and Kole (2008) and Clark *et al.* (2010). A range of molecular tools, including allozymes (protein-based markers), and a number based on detecting variation in DNA, such as restriction fragment length polymorphisms (RFLPs), amplified fragment length polymorphisms (AFLPs), microsatellites, and most recently, single nucleotide polymorphisms (SNPs) have been developed to determine the amount of genetic variation present in populations, the relationships between populations and interactions with wild stocks; track parentage; enable traceability; and provide markers for important economic traits (Liu and Cordes, 2004; Liu, 2007). Cheaper and more effective DNA-based markers have generally replaced allozymes and older DNA-based markers. Today, microsatellites and, increasingly, SNPs are the variants of choice for collecting genetic information. Nearly all the high-production species have some number of molecular variants available for such use. Usually this is a handful of polymorphisms (<10–20) most often used for population genetic work and assessing the level of variation within cultured populations. The number of species for which there is no information on wild stocks provides a useful proxy for those for which it is unlikely there are any markers available. Among the high-production species there are only five such finfish (11 percent) and none of the molluscan, crustacean or seaweed species lack these resources. However, 20–30 percent of low-production species appear to do so.

The information that even small numbers of polymorphisms have provided is that cultured populations frequently have reduced variation relative to wild ones. They often differ considerably in the frequency of genetic variants from the wild stocks from which they were derived, even after only one or two generations. Both effects can result from taking only a sample of the wild variation in stocking a culture system (a founder effect), breeding occurring from only a small number of individuals in the captured populations (low effective population size) and/or the effects of unintended or deliberate selection of breeders within the culture system. Each of these effects has been reported for finfish (Dunham, 2004) molluscs (Boudry, 2009) and crustaceans (Benzie, 2009). Suites of markers used to identify parents and their young (PT in the Tables) have been reported for far fewer species though – 26 finfish (Table 2), 6 molluscs (Table 3) and 5 crustaceans (Table 4) in total, and 9, 4 and 4 species, respectively, for the high-production species. So the tools exist for some species to be able to assess effective population sizes of cultured populations and to establish pedigree data from molecular markers and so potentially better manage inbreeding and mating schedules. They are used for cultivar identification, parentage assessment and to provide species identification and study geographical patterns of genetic

variation in the seaweeds *Laminaria* (Wang *et al.*, 2004; Bartsch *et al.*, 2008), *Porphyra* (Weng *et al.*, 2004) and *Undaria pinnatifida* (Wang *et al.*, 2006; Endo *et al.*, 2009). Recently, an assessment of tools for identifying the genetic origin of fish and monitoring their occurrence in the wild has been undertaken as part of GENIMPACT – a European network (Blohm *et al.*, 2007).

Resources for marking and mapping

The ability to use markers to assist the efficiency of breeding programmes by identifying molecular variants associated with traits of economic importance demands access to significant numbers of markers, and assessments of their relationships with each other and those traits. Sequence data can be used to identify variable sites that can be used as markers and to detect particular candidate genes known in other organisms to be important for key processes such as growth or disease resistance. The number of Expressed Sequence Tags (ESTs) or sequences of gene fragments that are major sources for marker discovery is a good proxy to indicate where such resources may exist. There are EST libraries with more than 100 ESTs for 27–34 percent of high-production species in all taxonomic groups (Table 1). However, the level of such resources needed for sound genomic work is on the order of 10^4 or greater, and only ten high-production finfish, six molluscs and five crustaceans have these. No aquaculture species has published values of 10^6 or greater. Large EST libraries are associated with additional resources such as large insert libraries (BACs or bacterial artificial chromosome and FOSMIDS or cloning vectors), and microarrays, although relatively fewer molluscs have these resources developed compared with finfish or crustaceans.

Genetic maps

Genetic maps exist for 24 finfish, 8 molluscan and 4 crustacean species in total, and 17, 4 and 4 species, respectively, of the high-production species. Only a handful use significant numbers of SNPs as markers (two finfish and one shrimp). Microsatellites were used as major markers in 88 percent of finfish species maps and 50 percent have AFLPs, while 100 percent of molluscan and crustacean species maps used AFLPs and 75 percent some microsatellites. The importance of marker type is that AFLPs do not mark the same position in a map based on a different set of samples, whereas microsatellites, SNPs and other markers do. AFLP markers themselves therefore do not have general applicability, and such maps are of limited use. Another key observation is that relatively small numbers of markers have been positioned on any one map. The highest number of markers is for rainbow trout at 1 359; only Atlantic salmon, Nile tilapia, common carp and giant tiger prawn are greater than 500, and no mollusc map exceeds 200. For comparison, the maps used to great effect in major agricultural crop and livestock species have several to tens of thousands of markers. Although work on channel catfish linkage mapping began in the 1980s and several maps were produced in the 1990s, the majority of finfish maps, and all molluscan and crustacean ones have been produced in the last decade, and all clearly improved in quality over time.

Markers for specific traits and quantitative trait loci

Among the high-production species, quantitative trait loci (QTLs) are reported for only nine finfish, two molluscan and two crustacean species. Most have fewer than ten QTLs and more than 20 are reported only for rainbow trout. Most are associated with growth, some disease resistance, feed conversion efficiency, tolerance of bacterial disease, spawning time, embryonic developmental rates and cold tolerance. A candidate DNA marker linked to infectious haematopoietic necrosis (IHN) disease resistance has also been identified in salmon. The reason for small numbers of QTLs being identified is that few studies measure the characters of interest in the same individuals in which the markers are assayed, fewer still corroborate the validity of the linkage observed in the initial mapping families in wider population studies, and the ability to finely map candidate genes is limited by the low marker density in most aquaculture species. Sex markers have been reported for shrimp, molluscs and several finfish and growth QTLs are most frequently reported, but few are used to date in marker assisted selection programmes (see below).

Marker assisted selection

Marker assisted selection (MAS) refers to selective breeding in which selection is based on the genotypes (Liu and Cordes, 2004) or on a combination of value estimates based on marker genotype and phenotypic trait data (Gjedrem and Baranski, 2009). MAS is particularly important for traits with low heritability, limited, late in life or after slaughter recording. Sonesson (2007) demonstrated that MAS could generate up to twice the total genetic gain of the corresponding non-MAS scheme in within-family selection. The large QTL for IPN resistance identified in Atlantic salmon was incorporated in MAS in Norway, increasing the rate of genetic improvement of this trait by up to 50 percent (Gjedrem and Baranski, 2009). A successful marker-assisted breeding for disease-resistance in an aquacultured species was the case of lymphocystis in Japanese flounder (*Paralichthys olivaceus*) (Fuji *et al.*, 2007). Genomic selection (Meuwissen, Hayes and Goddard, 2001) could be immensely beneficial for multitrait selection, but requires a relatively large number of markers, now practical in aquatic species, with the development of new sequencing technologies and whole genome and transcriptome sequencing.

Gene expression

The last decade has seen an explosion of activity in the isolation and characterization of individual genes. It is beyond the scope of this review to cover this literature, as genes are often isolated because of the interest of an individual researcher in a particular gene or gene group, often with no particular interest in any aquaculture application. So isolation, characterization and expression of single genes in one or more tissues for many of the species being cultured, irrespective of their production volume, have been reported. However, there are few programmes of significant scale designed to detect candidate genes of interest for genetic improvement programmes. For example significant

microarray resources have been developed for only 16 finfish, only 7 of which are high-production species (Table 2), 2 molluscs, *C. virginica* and *C. gigas*, but no crustaceans (Tables 3 and 4).

Other technologies

Sex manipulation

Sex manipulation is not used in molluscs (Tables 1 and 3), but sex reversal has been achieved in freshwater shrimp (Sagi and Aflalo, 2005) and crayfish (De Bock and López Greco, 2010) through surgery and/or by mating strategies using feminized males which produce all-male offspring when mated to normal males (Table 4). Similarly, mating strategies using physiologically or surgically sex-reversed finfish are used to produce single-sex populations which have the advantage of reduced variability at harvest and/or the use of only the faster growing sex for production (Dunham, 2004). Sex reversal is often achieved using gynogenesis or androgenesis, hence the co-occurrence of these technologies in the list in Table 2.

Gynogenesis and androgenesis

Mechanisms to manipulate sex, but which also aid discovery of new genes and understanding of the genetic control of key characters include gynogenesis (the production of young through excluding the male contribution and doubling the female one) or androgenesis (the production of young through excluding the female contribution and doubling the male one) (Dunham, 2004). Similar mechanisms for doubling chromosome complements are used to change the number of chromosome set copies (ploidy manipulation) to produce polyploid individuals (usually triploids), either because these grow faster than the usual diploids, or because they do not breed. Mitotic gynogens (produced during mitosis) and androgens are totally homozygous, and are therefore less likely to complete development because of the uninhibited expression of deleterious genotypes, and hence more difficult to obtain. They can be used to produce clonal lines. Meiotic gynogens are not homozygous because recombination during oogenesis mixes genes from the female and male parent before exclusion of the second polar body.

Application of these methods is not reported for crustaceans or molluscs, although clonal lines are reported for two molluscs, northern quahog hard clam (*Mercenaria mercenaria*) and Farrer's scallop (*Chlamys farreri*) (Tables 1, 3 and 4). Androgenesis is more rarely applied in high-production finfish species than gynogenesis, although this pattern is reversed in low-production species. Coupled with sperm cryopreservation, androgenesis may serve a major role in conservation of endangered species or stocks. One or another technique has been applied to 16 high-production finfish, but inbred clonal lines have been produced for only four: common carp, grass carp, Nile tilapia and rainbow trout (Table 2). Despite being genetically identical, individual performance within

these clones is highly variable. These do not play a major role in production, but the use of gynogenetic female lines and gynogenetic sex-reversed inbred male lines was critical in the Hungarian common carp crossbreeding programme.

Ploidy manipulation

Application of stress to early (single-cell) stages of fertilized eggs through pressure, temperature or chemical manipulation can increase the number of chromosome set copies and is used normally to make triploids (with three rather than two chromosome set copies) and rarely tetraploids. The latter are constructed so that triploids can be made by crossing tetraploid with diploid parents. At least experimental activity has been undertaken on about 40 percent of finfish and molluscs, but only 18 percent of crustaceans (Table 1). Practical application to industry has not been achieved for crustaceans, but has for a number of fish species (Dunham, 2004) and molluscs (Boudry, 2009) for both increased growth and use of sterile production stocks (Piferrer *et al.*, 2009). Large-scale application is made for oysters, particularly *C. gigas* in the United States industry.

Cryogenics

Cryogenics, the frozen storage of gametes (usually sperm), a technology that allows storage of genetic material and enables mating between parents that is otherwise difficult (e.g. when one sex is rare, or individuals come into reproductive condition at different times) or impossible (e.g. between generations of an annual species). Methods have been established experimentally for 20 percent of high-production finfish and molluscs and 45 percent of crustaceans (Table 1), but the level of its routine use in breeding programmes is hard to establish. Although the technology exists, the only cryobanks designed to store aquaculture genetic resources established so far are in the Institute of Fishery and Hydrobiology, Vodňany, Czech Republic, and recently for aquaculture in Brazil.

Genetic engineering

Direct insertion of specific genes to create a genetically modified organism (GMO) has been attempted in each of the four taxonomic groups (Table 1), although only experimentally for one high-production mollusc (*C. virginica*), three penaeid shrimp and the red swamp crawfish (*Procambarus clarkii*) (Tables 3 and 4). Introduction of DNA into crustaceans and molluscs is technically demanding and though achieved, the results have not been rewarding to date. By far more work has been done with finfish, including at least experimental work with 23 of the 44 high-production species (Table 2). This work has been reviewed by Kocher and Kole (2008) and despite the level of experimental work, particularly in the developmental fish models (zebra danio (or zebrafish, *Danio rerio*) and Japanese rice fish (or medaka, *Oryzias latipes*)) and in the salmonids, only two aquaculture species are the subject of larger trials, and none has achieved regulatory approval for commercial production.

Although genetic engineering is in an early phase with searches for algal promoters and effective means of gene transfer, the existence of haploid (gametophyte) and diploid (sporophyte) phases and clonal propagation of seaweeds suggests considerable scope for transgenic approaches (Minocha, 2003). Work on seaweeds as novel bioreactors is being addressed experimentally, with expression of targeted genes achieved in transformed explants in a number of cultured species, *Kappaphycus*, *Laminaria*, *Porphyra* and *Undaria* (Hallmann, 2007; Li *et al.*, 2009a). Additional biotechnological applications include the use of native and recombinant enzymes to assist the preparation of protoplasts, the use of which could allow genetic improvement through somatic hybridization (Inoue, Kagaya and Ojima, 2007; Reddy *et al.*, 2007). Genomic information is becoming available through sequence information held on international databases and will become increasingly useful with the completion of seaweed genome sequencing projects, including a *Porphyra* species.

Dispersal of farmed stocks

Terrestrial animals and plants were first domesticated about 12 000 years ago in about nine geographically restricted regions (Diamond, 1997, 2002). Archaeological and population genetic data show a rapid spread of these species from their regions of origin several thousand years ago to regions suited for major production (these data are summarized for both plants (FAO, 1997) and animals (FAO, 2007)). The first strains spread regionally and may have prevented independent attempts to domesticate that species. Therefore, those with restricted distributions (e.g. wheat, barley and peas) were subject to one domestication event, those with wider distributions to multiple domestication origins (e.g. pigs, horses, cattle and chickens), and independent domestication of the same or closely related species occurred where there were significant barriers to migration (e.g. potatoes, maize, peppers, beans and squash).

Several publications (Bartley *et al.*, 2009) have summarized how many aquaculture species have been distributed within, and far beyond their natural range. A number of finfish species were widely stocked for sport fishing (e.g. brown trout (*Salmo truttae*) and other salmonids, and centrarchids), often well beyond their natural range, and for more than a 100 years. Since then, many species have been introduced to new areas with a view to developing aquaculture industries. All of the high-production species listed in Tables 2–5 have been subject to exchange between local and regional populations for the purposes of aquaculture, and many distributed intercontinentally or worldwide. The role of alien species in Asian aquaculture and its links to food production were highlighted by De Silva *et al.* (2006) and De Silva *et al.* (2009), respectively. Extensive exchange of common carp has occurred for hundreds of years. Some 259 separate introductions of *Cyprinus carpio* strains have been recorded, and some strains recognized as local have originated from alien introductions with hybridization to local stocks in the distant past (Jeney and Jian, 2009). In many

cases, large-scale production takes place in regions far from the natural range of the species, and relatively little, if any, in its native range (e.g. redclaw crayfish found naturally in tropical Australia is produced mainly in China; the east Pacific endemic whiteleg shrimp *Litopenaeus vannamei* is produced in North and South America and throughout Asia; Atlantic bay scallop (*Argopecten irradians*) found in North America is produced mainly in China; Atlantic salmon are produced in Chile and Australia as well as in their natural range in Norway and Canada; Nile tilapia, an African endemic, is mainly produced in Asia). Extensive movements of wild-caught marine finfish seed have been documented for Asia by Nguyen *et al.* (2009).

Crayfish species have been spread across several continents, in many cases for restocking or to provide alternative wild fisheries in circumstances where the naturally occurring species had previously declined. Other species used in aquaculture have spread because of their natural invasive capabilities, such as the Chinese mitten crab, *Eriocheir sinensis*, thought to have spread in ship ballast waters. All the major cultivated seaweed species have been moved extensively. The primary development of *Laminaria japonicus* and *Porphyra* culture was in Japan, but the export of key varieties to China led to greatly increased production there. Cultivated varieties of *Kappaphycus alvarezii* have been introduced to many parts of the world for the development of seaweed farming and are now produced in the Philippines, Indonesia, Malaysia (Sabah), Fiji and Tanzania (Munõz, Freile-Pelegrín and Robledo, 2004).

The movements parallel the history for terrestrial species, but the rapidity is greater for aquaculture species, reflecting the ease of egg and larval transfer, the globalization of trade and the speed of present day travel. The extensive movement of terrestrial and aquatic species has given rise to concern about the impacts of alien species through the establishment of feral populations, their interactions in the ecosystems to which they have been introduced and the transfer of diseases, or associated commensals, to endemic biota. Negative impacts have been described in all these regards, with feral populations of some penaeid shrimp, molluscan and finfish species established outside their natural ranges (Bartley *et al.*, 2009). Hybridization with related species (e.g. in crayfish species (Perry, Lodge and Feder, 2002) and catfish (Senanan *et al.*, 2004)) resulting in the loss of regional endemics; loss of regional variation or introgression of genetic material from genetically differentiated populations from different parts of a species' range resulting in modification of local wild stocks have also been documented (Cross, 2003; McGinnity *et al.*, 2003). However, other studies on tilapia and carps have shown no impacts or impacts that are judged acceptable by local communities in view of the social and economic benefits arising from culture (Arthur *et al.*, 2010). There is particular concern about genetic exchange between wild stocks and GMOs.

Wild genetic resources

Molecular tools revolutionized understanding of the genetic diversity in wild populations from the late 1960s, revealing large amounts of variation, and often considerable differences in gene frequencies within species over their geographical range. The relevant tools have recently been assessed by Blohm *et al.* (2007). The development had important consequences for the conservation and exploitation of natural resources (Thorpe, Sole-Cava and Watts, 2000). In fisheries, cryptic species or spatial and temporal genetic structure were detected, indicating that what was thought to be one fishery was exploiting several stocks that should be more appropriately managed separately. Rapid life history changes in fish and shellfish stocks under intense selection pressure from fisheries, resulting in, for example, early maturation and smaller adult sizes in fished populations, were demonstrated. Many species with high dispersal capability appear not to move as much as expected, and therefore may not recolonize depleted regions, and regional genetic differentiation is likely. Strong evidence has been obtained that the molecular differentiation of local stocks of fish, and salmonids in particular, reflects adaptation to local environments. These findings have important implications for the effective management and exploitation of natural fisheries resources and are discussed in more detail in several reviews (see papers in Hauser, Waples and Carvalho, 2008).

Molecular work has shown cryptic taxa exist in what are considered to be single aquaculture species (e.g. the recent discovery of a cryptic species of *Marsupenaeus japonicus* in Asia (Benzie, 2009); of cryptic tuna species by COI DNA barcoding (Yancy *et al.*, 2008), and confirmed species complexes in several groups including the crab *E. sinensis* (Li *et al.*, 2009b)). Difficulty in assessing the numbers of species farmed because of poor taxonomic distinction applied to farmed stocks is particularly important for molluscs and aquatic plants, but can be significant in finfish, where cultured stocks can be unrecognized interspecies derivatives. Oysters comprise species complexes in Asia that are poorly understood, and the catch-all title of Pacific oyster probably includes several species (Klinbunga *et al.*, 2005). Algae are often referred to by genus name alone, and there are significant difficulties in determining cryptic taxa in species where there is known to be substantial, environmentally induced, morphological variation (Wikfors and Ohno, 2001).

However, molecular tools to provide accurate molecular diagnosis of species provide tools for traceability of products, forensic assessments of products and introductions to the wild, and interactions between wild and cultured stocks (Teletchea, 2009). They have been used to identify and analyse the pathways used by invasive species (e.g. *E. sinensis* (Dittel and Epifanio, 2009)), and the nature of genetic interactions between wild and cultured stocks of salmon (e.g. McGinnity *et al.*, 2003). Naylor *et al.* (2005) presented a thorough analysis of the risks posed by escaped salmon from net-pen aquaculture: risk of feral

stock establishment; competition with wild fish for mates, space and prey; pathogen transmission; and most relevant to this review – risks associated with genetic interactions with wild stocks. Atlantic salmon has been shown to genetically affect wild populations of other salmonids as well (e.g. sea trout (*Salmo trutta*) (Coughlan *et al.*, 2006)). The effects of cultured species on their respective wild populations are visible in the last two or three decades also with the Mediterranean gilthead seabream and European seabass (Dimitriou *et al.*, 2007). Escaped hybrid catfish (female bighead catfish, *Clarias macrocephalus* × male North African catfish, *C. gariepinus*) from farms in central Thailand may interbreed with *C. macrocephalus* individuals in the wild (Na-Nakorn, Kamonrat and Namsiri, 2004; Senanan *et al.*, 2004). In contrast, no effects of cultured catfish were observed on wild stocks by Simmons *et al.* (2006). Considerable shifts in gene frequencies in some wild populations subject to high levels of introductions have been reported (e.g. Hindar, Ryman and Utter, 1991; Waples and Do, 1994). These often occur where populations are subjected to sustained restocking from hatcheries, and there is evidence of short-term advantage for hatchery-produced stocks relative to wild ones, but poorer performance under stress, and presumably over longer time periods, than wild individuals. However, the burgeoning research on both terrestrial and aquatic alien introductions shows large variation in the extent and timing of their effects, and much research needs to be done to understand these. Recent work has shown how wild populations change in gene frequency over short times, and that they are selected by a changing environment (e.g. Clutton-Brock and Pemberton, 2004). The ability of fish to track their environment through changing genetic constitution will bring into question how to interpret genetic difference detected spatially at one time point and requires greater application of evolutionary science to these issues.

To avoid the risks of alien species, it has been suggested it is better to use local species for aquaculture. In a region such as the lower Mekong, there is a trend to encourage the use of indigenous species for aquaculture and stock enhancement purposes (e.g. Sverdrup-Jensen, 2002; Ingthamjitr, 2009), driven by the need to mitigate purported negative impacts from exotic species. Significant downsides to this approach that are not usually discussed include the fact that cultured indigenous populations are more likely to be able to interbreed with local wild stocks. Managing the cultured stock as one would a hatchery stock designed for wild population enhancement, and so reduce genetic impact would prevent the development of a line that was efficient for food production (De Silva *et al.*, 2009). In addition, the need to develop effective understanding of the biology of a given species, including husbandry, feeds and reproductive control prior to being able to undertake practical genetic improvement on an industrial scale means that there will be a lead time of a decade or likely far longer to bring such species into effective production.

A technical solution to this would be for the development of sterile production stocks, and highly secure facilities for the core breeding population of cultured

species (Cotter *et al.*, 2002; Mair, Nam and Solar, 2008). However, for some, the use of sterile production animals gives rise to concerns about ownership of the breeding stock. These examples illustrate the complex interaction of technical capability, production needs, environmental concerns, and issues of ownership and benefit sharing.

Strategic consequences of biological constraints

In aquaculture today, a small number of now widely spread species that are particularly easy to farm dominate production, as in agriculture. While production of some new species has increased and replaced previously higher-ranking species, examples are few (an exception is pangasiid catfish), and usually involve changes in ranking of species that have been cultured for some time. It is possible that new major production species will emerge in aquaculture, as many species are still being tested. The market and ecological concern also drives choice of species/strain to be farmed, but while these issues may attract investment or drive additional work to overcome technical challenges, the available data suggest that those species that are easy to farm are those most likely to become widely farmed. Just as some new top performers may be found, some species that are recorded as domesticated now may be discarded in the future, or support only small regional production. Already, in shrimp, of more than 20 species for which aquaculture technologies were successfully developed, only seven now provide 99 percent of shrimp production. Two species for which there are specific pathogen free (SPF), genetically improved stocks supply 86 percent, one of which, *Litopenaeus vannamei*, now dominates world supply. With production systems, supply chains and retailers tailored to this product, competition from other species is made more difficult.

The rapid gains of modern genetics that were achieved with terrestrial species during the last century were obtained using a resource which had already undergone thousands of years of domestication. A wealth of information on physiology, disease, behaviour, reproduction, biochemistry and routine husbandry was available for these species by then. This information is often lacking for aquaculture species, and it takes time to obtain as experience is gained in the husbandry of a new species in different environments. Basic research can change practical applications in ways never imagined by researchers. However, many incremental findings are needed to assimilate new knowledge, and the contributions of commercial producers and users are critical to the practical application of scientific knowledge and the creation of demand for products (Wikfors and Ohno, 2001). The need to have an integrated application of a variety of technologies to sustain selective breeding programmes has slowed, and will continue to slow, the pace of genetic improvement over a broad front. Important production species which are not domesticated, and for which the only source of seed supply are wild stocks include the Japanese eel (*Anguilla japonica*), flathead grey mullet (*Mugil cephalus*), milkfish (*Chanos*

chanos) and mandarin fish (*Siniperca chuatsi*), and for many other species the principal source of seed is still from the wild (Mair, 2007).

The application of molecular genetics and biotechnological tools on an industry-wide scale requires the stable platforms of fully domesticated (probably more than the three generations in culture arbitrarily chosen in this paper as a definition for domestication of aquaculture species), if not genetically improved stocks. The increasing simplicity and decreasing cost of molecular and genomic work means that the initial research undertaken to find markers or candidate genes is relatively easy to undertake. The longer-term work to assess their effects in whole organisms is dependent on having knowledge of biochemistry, physiology, etc. and the means to undertake expensive experiments to determine their effect and construct practical applications. Genomic work for most aquatic species is at an early stage with maps based on relatively few markers, few QTLs and only one or two used to date in marker assisted selection. Technical difficulties and consumer resistance means there is little practical application of GMO technology so far.

Conclusions

The analysis of the current state of the art is important for considering pathways for future development. No one pathway would sensibly be followed to the exclusion of others. However, these results suggest that with respect to the aims of increasing food production and reducing risk to biodiversity, that 1) there be a greater focus on developing selective breeding programmes, and 2) that there might be greater return by focusing on easily farmed species already in production rather than a concerted search to develop new species.

Key shortcomings

Ten years ago only 1–2 percent of farmed fish and shellfish production was thought to be derived from modern genetic improvement programmes (Gjedrem, 2000). If it is assumed that all the production from the species recorded to have a genetic improvement programme, however small, is from genetically improved stocks, then, using production figures for those species from FAO data (FAO, 2009a), an upper limit of 15 percent of molluscan, 67 percent of crustacean, 76 percent of finfish, 99 percent of seaweed and 73 percent of total aquaculture production would be from improved stocks. However, more detailed information from particular industry sectors indicate these figures are too high (Bartley *et al.*, 2009). In the case of crustaceans, where better information is available, almost all production for *L. vannamei* is from improved sources, but most production for all other species is not, providing an estimate of 45 percent of crustacean production from improved sources (Benzie, 2009). In the case of the main carp species, assuming that only 10 percent of carp production is from improved sources means only 7 percent of fish production and 38 percent of all fish production is genetically improved. These calculations serve to illustrate the

dearth of reliable information on genetic resources used in aquaculture and the need to improve this. The present analysis, based on production identified to species, accounts for only 70 percent recorded by FAO for aquaculture – thus, data on almost a third of world production is absent.

In addition, plant resources were poorly represented. Although by far the major production, only seaweeds are discussed in any detail, and more than 100 species have been tested for aquaculture (Ohno and Critchley, 1993), and cultured aquatic plants comprise a range of higher plants including reeds, *Lotus*, water spinach (*Ipomea aquatica*), and water cress, but statistics on these individual groups are difficult to access. In recent years, there has also been considerable growth in the use of microalgae as feeds for aquaculture species, and there is increasing use of some microalgal species (e.g. *Spirulina*) for human food consumption, often as a nutraceutical (Wikfors and Ohno, 2001), and for a range of biotechnologies, reviewed in Hallmann (2007).

Resources available to assist best practice

A number of resources have been developed to provide guidance on best practice in breeding and genetic improvement in aquaculture to farmers, technical staff, extension and development officers and policy-makers (e.g. Tave, 1995, 1999; Gjedrem, 2005). Direct environmental effects of the aquaculture process on land use and effluents have long been recognized and have led to the development of manuals and codes of practice for aquaculture internationally and nationally for various sectors of the industry (e.g. in shrimp farming: FAO/NACA/UNEP/WB/WWF, 2006). The importance of effects of biodiversity itself took longer to appreciate (Beveridge, Ross and Kelly, 1994; Pullin, 1996). The growing recognition of the complexity of genetic variation within species, the presumed adaptive nature of this variation, and the potentially deleterious effects of breeding between aquaculture populations (whether local or introduced) and local wild stocks have led to the development of strategies to assess and monitor risk and implement improved management practices (e.g. Pullin, Bartley and Kooiman, 1999; FAO, 2008). These approaches extend the procedures developed for the introduction of alien species, the threats of disease transfer and potential ecological impacts which have been appreciated for much longer (Pullin, Bartley and Kooiman, 1999; Bartley *et al.*, 2005, 2009, FAO, 2008). However, it is difficult to assess the extent to which these voluntary codes have assisted aquaculture development and ameliorated negative impacts.

Guidelines for better-practice approaches to the development of domesticated stocks all suggest paying attention to some, or all, of the following criteria:

- knowledge of genetic resources available;
- choice of appropriate resources to include in cultured population;
- adequate genetic variation in founder stocks;
- adequate management of the stock to avoid deleterious inbreeding;
- environmental impact of cultured stocks on wild populations;

- maintenance of genetic variety in cultured populations and protection of variation in wild stock;
- introduction of alien farmed species to new locations (outside their natural range);
- issues of ownership and benefit from domesticated stock; and
- food security

The global and national legal frameworks underpinning the ownership and use of natural resources have changed in the last 20 years – biodiversity was once considered the heritage of all mankind, but sovereign nations own the biodiversity within their boundaries (CBD, 1994). However, the development of improved strains for culture demands considerable investment and the application of key knowledge. Access to biodiversity and determination of the ownership of the resulting strains or intellectual property require effective mechanisms to assess appropriate benefit sharing. This issue is all the more acute because of differences in the global distribution of producers and consumers of aquaculture products. Aquaculture growth in developing countries is double or more that of developed nations, with 60 percent of world production coming from China (FAO, 2010a). There are differences in the location of skilled technologists and investors, the source areas of natural stocks and the locations of most cost-effective production. A doubling of aquaculture production will need to replicate agriculture development in far less time than it took to domesticate terrestrial species, in circumstances where the likelihood sites will be prioritized for food production is reduced and which demand new approaches that take account of the risk to natural biodiversity. There are, then, a range of technical, social, political and commercial issues to be considered in increasing food production from aquaculture. For example, Brummett and Ponzoni (2009) note the risks to native biodiversity need to be assessed, but that the use of improved lines of tilapia could provide immediate economic benefit, and the development of new improved lines should be encouraged as opposed to using available wild stocks.

The change in ownership of biological diversity resulting from the Convention of Biological Diversity (CBD, 1994) led to the development of the Bonn Guidelines on access to genetic resources and fair and equitable sharing of the benefits arising out of their utilization (CBD, 2002). However, the fact that policy development and legislation relating to different aspects of development are often under different departments with different key goals can lead to significant conflict. This is common circumstance in government, and in the present context, much of the development of the processes related to the CBD has been undertaken by environment departments, while responsibility for food production and industry development and research and development are in different departments. The possible impact of CBD-related policies on food production has only been recently been appreciated, and while environmental organizations are aware of the developments, much of industry, and some departments of trade, commerce

and industry are not (see papers in Bartley *et al.*, 2009). There is a need to undertake formal surveys to establish the extent and depth of understanding of these policies outside the specialist groups developing them.

Despite the existence of useful publications on policies, codes of practice and best practice, their implementation is variable because of gaps in dissemination of the information, lack of effective technologies or over-riding factors of economy and/or practicality.

Summary

There is scope for increasing aquaculture production by accessing new regions for fish farming, such as the open sea, but this will require innovative approaches and high levels of investment. Coastal and inland aquaculture sites are limited and their use is subject to strong competition. More production from existing areas will be necessary to increase aquaculture output. The bulk of aquatic animal production is based on freshwater species where these constraints are greater and impacts on wild resources potentially higher. Aquaculture has shown sustained growth in production for 20 years through increasing the number of species farmed, but mainly through increasing production of a few of these. Aquaculture is subject to a more rapid application of domestication and genetic improvement than occurred in the historical development of agriculture. Selection programmes and advanced technologies are being applied in the early stages of domestication of many new species.

However, major constraints relating to the fundamental attributes of a species, the lack of accumulated knowledge concerning biology and husbandry, and the restricted levels of investment limit the effectiveness and speed of application of these techniques. Many high-production species are not subject to modern methods of genetic improvement. Even in many species where a domesticated line has been established, an unknown but large proportion of seed supply for industry production still relies on access to wild genetic resources. Contribution of genetically improved strains to total aquaculture production is still limited compared to that in terrestrial species. Continued large-scale use of wild sources for seed supply can have large impacts on the wild stocks and effectively imposes additional fishing pressure on them (Mair, 2007). It is imperative that closed breeding populations are established to reduce these effects, to obtain improved efficiencies through selection and the option to develop stocks with reduced capacity to interact with wild populations.

The risks to natural biodiversity, the source of useful genetic resources in the future, are real. Application of population genetics and evolutionary biology to aquatic species has increased understanding of genetic biodiversity in the last two decades. However, the available data vary in quality and quantity. There is a need for more high-quality studies with improved coordination and collaboration between groups with complementary skills. Continued production of scientists

that can provide the depth of analysis and interpretation is needed to better understand the nature of interactions of wild and cultured populations and advise how these can be managed.

The few successful genetic improvement programmes have all involved collaboration of several sectors of government, industry and NGOs, often internationally, to achieve technical and practical success. Sometimes these were established outside the natural range of the species and by investment from countries/companies other than the major producing regions or the place of origin of the original stocks. These circumstances indicate the mutual dependence of different sectors in achieving effective food production, and the need to appreciate their relative strengths and roles, and their rights in relation to access and benefit sharing. Systems to assist dialogue among those with responsibility for achieving varied, divergent and sometimes contradictory goals of conservation and food production will be vital.

The lack of effective means to track the contribution of various genetic resources means estimates of their contribution to world food supply range from 7–70 percent in the case of finfish and anywhere between 20 and 70 percent of total production, depending on assumptions. There is a critical need to improve knowledge of the state of the world's aquatic genetic resources. Timely information on the status of these and the technologies in use in food production systems is critical in order to assess and guide the process of sustainable aquaculture development.

There is a clear role for the FAO in conjunction with regional organizations and institutions and national governments, to assist that dialogue, to continue to better document aquatic genetic resources available in the wild and in current production systems through the Multi-Year Programme of Work of the Commission on Genetic Resources for Food and Agriculture. There is a need for FAO, the Consultative Group on International Agriculture Research (CGIAR), other regional and international organizations dedicated to aquaculture development and individual states to better disseminate information on best practice and to assist dialogue between groups focused on different aspects of development and conservation in order to develop effective sustainable use of aquatic genetic biodiversity.

Recommendations

The responsible use and conservation of aquatic biodiversity for sustainable aquaculture therefore requires the use of efficient mechanisms for production, and technologies to minimize environmental and genetic impact.

Ten years ago, a review of the status of aquaculture genetics for the Conference on Aquaculture in the Third Millennium (Dunham *et al.*, 2001) recommended a series of actions to encourage the continuing development of genetic

improvement in aquaculture and the increased characterization and protection of wild genetic resources. This was to be achieved by:

- encouraging networking of experts, CGIAR, other regional and international organizations dedicated to aquaculture development;
- improving training programmes in hatchery processes, genetic management and breeding skills;
- promoting greater investment in a range of genetic research; and
- promoting stronger national, regional and international controls on the exchange of genetic material, and
- promoting stronger enforcement of existing legislation.

In the ten years since then, it is clear that there has been increased activity in all these areas, but that continued effort is needed on all.

The analysis carried out in the present synthesis has confirmed the main patterns of technology use described ten years ago. However, consideration of the patterns of use of these technologies and the speed with which they are applied to large-scale food production has emphasized the central role of selectively bred stocks and the range of constraints to achieving stable programmes that ensure their maintenance for aquatic species. It has demonstrated that information on genetic resources is limited and often difficult to access, particularly in relation to the use of material in production systems.

There has been a considerable increase in knowledge of wild resources and of impacts of introduced species, and there are shortcomings in the data available concerning the wild resource, the nature and extent of genetic improvement and its impact in particular circumstances. Interpretations are not necessarily straightforward and improved skills for this are required.

Recommendations for expert panel theme 3.1 were to:

1. Improve information on the state of aquatic genetic resources including wild populations, cultured strains; the state of application and benefits of genetic technologies; and the status of, and impacts on, wild populations, including the effectiveness of technologies designed to mitigate such effects. This improved information should be shared through appropriate mechanisms such as regional networks, reporting mechanisms to FAO, and FAO's work towards a State of the World on Aquatic Genetic Resources with the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA).
2. Better focus investment in genetic R&D on establishing sound genetic resource management programmes with clear objectives, and which provide the necessary foundation for application of a variety of other technologies and encourage their application to a) production and b) wild aquatic genetic resource protection.
4. Encourage exchange among the diverse groups needed for better understanding of aquaculture and conservation activities and improved

- technology transfer by, e.g. continued dissemination of sound resource material and advice already available.
5. Strengthen the foundation for science-based risk analysis and control (through increased understanding, knowledge, technology development and regulatory capability) of interactions between wild and cultured stocks. This can be achieved by increasing the breadth and depth of case studies and encouraging the application of the precautionary approach.
 6. Access to and exchange of aquatic genetic resources has played a major role in the rapid growth of aquaculture. Unlike terrestrial plant and animal genetic resources that were domesticated thousands of years ago and maintained by traditional knowledge, aquatic organisms have only been domesticated recently. A significant portion of that process has been accomplished using high levels of technological and financial input by private and public/private partnerships in areas far away from the native range of the species concerned. Access/exchange must be continued with adequate risk analysis, and benefit sharing must be considered. In formulating policies and laws, the unique character of AqGR must be incorporated.

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Where a reference is given in the full reference list to the present paper only the author and date is given here. For references only listed as a source for data in the Tables, a summary reference to that source is given below.

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Addressing aquaculture-fisheries interactions through the implementation of the ecosystem approach to aquaculture (EAA)

Expert Panel Review 3.2

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Abstract

This review addresses how the ecosystem approach to aquaculture (EAA) can optimize aquaculture-fisheries interactions considering different spatial scales from farm, aquaculture zone and watershed through to the global market. Aquaculture and fisheries are closely related subsectors with frequent interactions, largely due to the sharing of common ecosystems and natural

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resources. Interactions are also born from the flow of biomass from fisheries to aquaculture through fish-based feeds (e.g. fishmeal, fish oil and trashfish), through the collection of wild seed and brookstock, and genetic resources and biomass transfer from aquaculture to fisheries through culture-based fisheries (CBF) and escapees. Negative effects include modification of habitats affecting fisheries resources and activities (e.g. mangrove clearing for shrimp ponds, seabed disturbances through anchoring of aquaculture cages or pens, damage to seagrasses, alteration to reproductive habitats, biodiversity loss). Eutrophication of waterbodies due to excess nutrient release leading to anoxia and fish mortality can also impact negatively on biodiversity and wild fish stocks. Release of diseases and chemicals also imposes some threats on fisheries.

Yet there could be beneficial impacts; for example, aquaculture is increasingly contributing to capture fisheries through CBF and could contribute to restore overfished stocks. Aquaculture can offer alternative livelihoods to fisherfolk, providing increased opportunity to them and also to their families, and especially to women. Aquaculture-increased production and marketing can also enhance and indirectly improve processing and market access to similar fishery products.

The ecosystem approach to aquaculture (EAA) is a strategy for the management of the sector that emphasizes intersectoral complementarities by taking into account the interactions between all the activities within ecologically meaningful boundaries and acknowledging the multiple services provided by ecosystems. The main objective of this review is to understand the status of aquaculture-fisheries interactions associated with the biological, technological, social, economic, environmental, policy, legal and other aspects of aquaculture development and to analyze how these interactions are or could be addressed with an EAA. Therefore, the review involves aspects of scoping, identification of issues, prioritizing, devising management tools and plans for minimizing negative effects and optimizing positive ones within the context of social-ecological resilience, at different relevant geographical scales.

Many of the management measures suggested in this review must involve not only EAA but also an ecosystem approach to fisheries (EAF), especially to deal with issues such as fishery of wild seed and the management of fisheries to produce fishmeal/oil for pelleted feeds or for direct feeding with wet fish.

The implementation of EAA and EAF should help to overcome the sectoral and intergovernmental fragmentation of resource management efforts and assist in the development of institutional mechanisms and private-sector arrangements for effective coordination among various sectors active in ecosystems in which aquaculture and fisheries operate and between the various levels of government. Ecosystem-based management involves a transition from traditional sectoral planning and decision-making to the application of a more holistic approach to integrated natural resource management in an adaptive manner.

KEY WORDS: *Aquaculture-fisheries interactions, Ecosystem approach to aquaculture, Culture-based fisheries, Food security, Integrated management, Stakeholder participation.*

Introduction

Background

Aquaculture and fisheries¹ are subsectoral activities that often can depend on the same natural resources and share the same ecosystem and spatial boundaries, even global boundaries when aquaculture consumes fishmeal from far away fisheries. Both sectors can impose external costs or benefits on each other and compete in downstream markets. They have close and complicated interactions with each other directly or indirectly, as the result of environmental changes caused by one or the other. Effective implementation of an ecosystem approach to fisheries (EAF) (FAO, 2003)/ecosystem approach to aquaculture (EAA) (FAO, 2009) will require a good understanding of such interactions, mutual impacts and potential synergies.

The two subsectors have interacted closely ever since aquaculture came into being. In ancient times, fish farming originated from the collection of wild seed for further fattening and growth in human-made enclosures; thus, aquaculture used to rely completely on fisheries resources, depending on seed supply from natural stocks. Along with the progress in aquaculture-related technology such as controlled seed production in hatcheries, the dependency on wild seed has declined; and we are moving towards a phase where aquaculture can potentially produce seed not only to supply culture production but also to stock into wild resources, usually known as culture-based fisheries (CBF) (see Lorenzen *et al.*, 2000; Lovatelli and Holthus, 2008). Thus, wild-caught seed as an output from a capture fishery can be considered as an input to aquaculture. Similarly, seed output from a hatchery when used for stock enhancement in CBF can be considered as an input to capture fishery.

Another clear interaction and strong aquaculture dependency on fishery is the use of pelagic resources for the production of fishmeal and fish oil and the use of bycatch or trash fish as feeds for aquaculture. Indeed, aquaculture has been criticized for putting additional pressure on pelagic fishery resources for the production of pelleted feeds (Tacon *et al.*, 2012).

Aquaculture can also negatively affect fisheries through the disruption of natural habitats and sensitive ecosystems for the construction of aquaculture farms. The excessive nutrient discharge from farms that could cause eutrophication (Gowen, 1994), the escape of farmed organisms (Thorstad *et al.*, 2008) and

¹ In this review, farmed fish and fish from capture fisheries include all aquatic organisms that are considered in capture fisheries and aquaculture (e.g. fish, crustaceans, molluscs, etc.).

the use of chemicals and fertilizers (Soto *et al.*, 2008) can all negatively affect fisheries. However, aquaculture can affect fisheries in positive ways; for example, by providing alternative livelihoods to fisherfolk, including the postharvest processing and marketing of aquaculture products and also by enhancing fisheries (including overharvested stocks) through hatchery-produced seed. This review describes the likely interactions in more detail and provides a management perspective with an ecosystem approach

The EAF and EAA management approach ensures sustainable fish production and nutritional benefits from both subsectors and facilitates the integration between them. Such integration takes into consideration the multiple uses of common aquatic resources and the full set of ecosystem services and functions they provide, as well as the economic, social and cultural values that people attach to these services.

Objectives

The main objectives of this thematic review are to present an overview of the aquaculture-fisheries interactions and to provide ways to minimize those that are negative while optimizing positive ones, using an ecosystem approach to the management of both sectors but focusing on aquaculture. The process to achieve these goals is also designed to promote greater interaction and wider participation during the review process, as well as involvement of a wide cross-section of different stakeholders in aquaculture development. An attempt is also made to assess the extent to which the aquaculture-fisheries interactions have been recognized and managed, thereby contributing to the implementation of the Bangkok Declaration (NACA/FAO, 2001).

This review focuses more on the effects of aquaculture on fisheries rather than on the effects of fisheries on aquaculture, since the latter are mostly positive (feeds, seeds, etc.). We thus concentrate on minimizing aquaculture's negative impacts and maximizing its benefits (e.g. through CBF).

General scenarios for the sector

The current fisheries scenario

Global capture fisheries production in 2008 was about 92 million tonnes, with an estimated first-sale value of USD91.2 billion, comprising about 82 million tonnes from marine waters and a record 10 million tonnes from inland waters (FAO, 2010a). The world's catches have been more or less stagnant or even declining during the past decade. Many fish stocks are widely reported to be in a state of serious decline. The Food and Agriculture Organization of the United Nations (FAO) reports that nearly 80 percent of world fish stocks are fully or over exploited (FAO, 2010a). This situation may pose a threat to aquaculture, including limitations to seed supply but mainly through the production of fishery-based feeds. On the other hand, the current fisheries situation increases the demands and expectations on aquaculture as fish supplier for the next decades and future

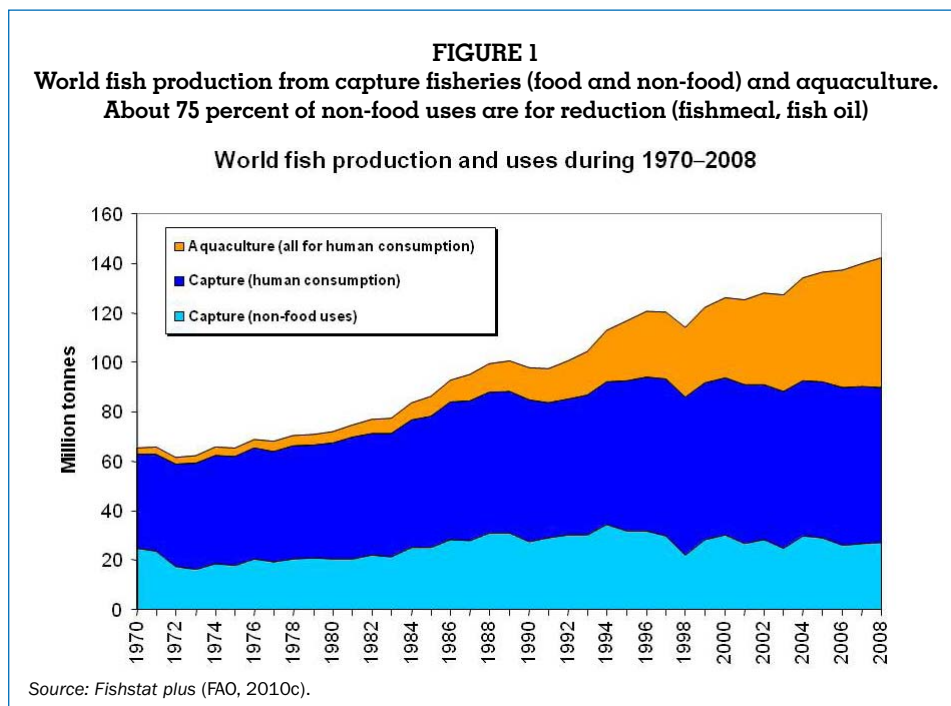
generations. The situation also offers an opportunity for aquaculture to supply and enhance fisheries through the provision of hatchery-produced seed.

Further growth of aquaculture

Aquaculture continues to be the fastest-growing animal food-producing sector and to outpace population growth, with per capita supply from aquaculture increasing from 0.7 kg in 1970 to 7.8 kg in 2008, an average annual growth rate of 8.3 percent (FAO, 2010a). Considering the fisheries scenario described above, aquaculture will most likely overtake capture fisheries as a source of food fish within the present decade. From a production of less than 1 million tonnes per year in the early 1950s, production in 2008 was reported to be 52.5 million tonnes with a value of USD78.8 billion, representing an annual growth rate of nearly 7 percent.

World aquaculture, including CBA, is heavily dominated by the Asia-Pacific region, which accounts for 89 percent of production in terms of quantity and 78.7 percent in terms of value. This dominance is mainly due to China's enormous production, which accounts for 62.3 percent of global production in terms of quantity and 49 percent of global value.

Figure 1 shows the trends in capture fisheries (both for direct consumption and other uses) and aquaculture. Part of the non-food uses (i.e. fishmeal and fish oil) is being transformed into aquaculture, although as seen in the figure, aquaculture increase does not seem correlated to fishmeal fisheries.



Implementing the EAA

What is the EAA and why is it needed?

Aquaculture should try to not compromise fisheries, but should seek to complement it by providing a net increase of fish output and food security as the global population keeps increasing and more food fish is needed. A sustainable increment of aquaculture output therefore requires an ecosystem perspective. There is an increasing recognition of the need to move towards more holistic fisheries and aquaculture management planning frameworks. However, the practical approach and application of ecosystem-based planning and management remains challenged by a poor understanding of this approach and the need for considerable policy reforms (Soto *et al.*, 2008).

Countries worldwide are also attempting to implement a diverse array of aquaculture regulations to control inadequate development of the sector. Yet some constraints persist that do not allow aquaculture and fisheries interactions to be adequately addressed. These often include:

- lack of awareness and understanding of such interactions in the context of ecosystem processes;
- lack of appropriate connection between ecological and social processes;
- lack of consideration of relevant boundaries and a multiple-scales approach, when appropriate; and
- lack of integrated multisectoral planning and management involving aquaculture and fisheries.

The FAO *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995) provides a global framework for responsible fisheries (including aquaculture). Nonetheless, member countries, fisheries organizations and fisheries stakeholders require a practical framework to implement the recommendations of the CCRF. The ecosystem approach to management of fisheries (EAF) and aquaculture (EAA) provides such a practical implementation framework where the objectives of responsible and sustainable fisheries and aquaculture can be translated into practical implementation at the national and local levels. This review will focus mainly on management from the aquaculture perspective.

“An Ecosystem Approach to Aquaculture is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems” (FAO, 2010b).

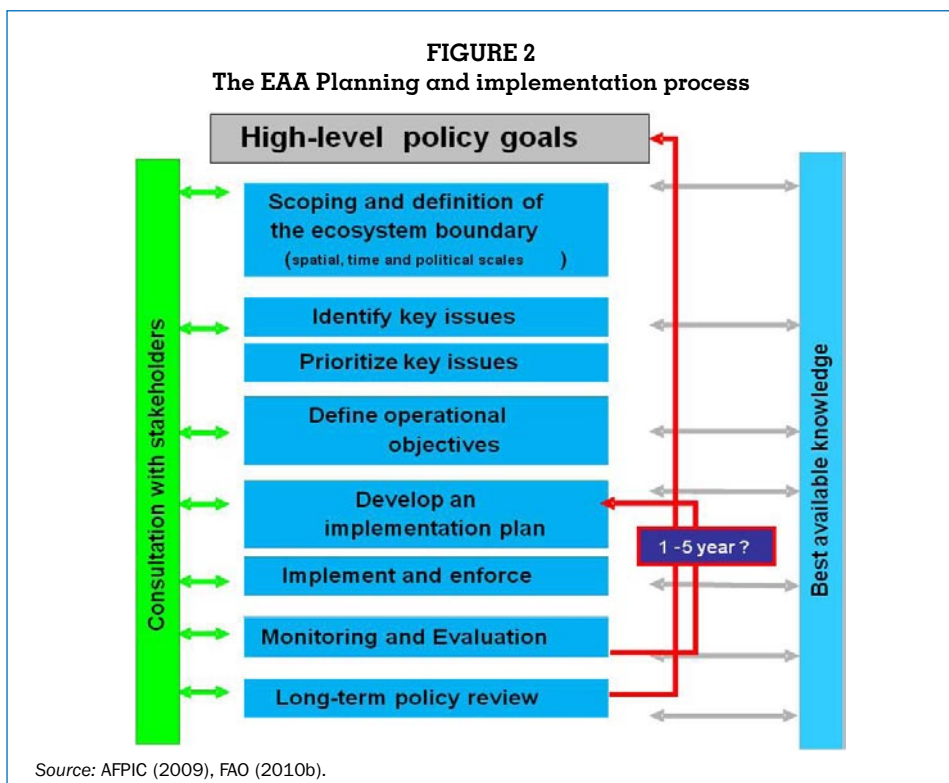
The EAA builds on the conceptual frameworks of the ecosystem approach as set by the Convention on Biodiversity (CBD) (UNCBD, 1992) and the ecosystem approach to fisheries (EAF) (FAO, 2003, 2009), as well as initiatives related to planning and management for sustainable coastal aquaculture development (e.g. GESAMP, 2001).

As a strategy to ensure that aquaculture contributes positively to sustainable development, the EAA should be guided by three main interlinked principles (FAO, 2010b):

- Principle 1: Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society.
- Principle 2: Aquaculture should improve human well-being and equity for all relevant stakeholders.²
- Principle 3: Aquaculture should be developed in the context of other sectors, policies and goals.

The EAA as a “strategy” should be the means to achieve or fulfil a higher policy level that reflects relevant national, regional and international development goals and agreements. Two elements are fundamental throughout the process: i) to collect and use all the best available information and ii) to have a broad stakeholder participation.

To implement the strategy successfully, it is necessary to translate the relevant policy goals into operational objectives and actions. The high-level policy should ensure or facilitate sustainable net fish production for food and livelihoods” (Figure 2).



² Especially the local communities where aquaculture takes place.

Implementation of the EAA has several steps, similar to those in the EAF. The first step, the scoping (Figure 2), requires defining the spatial boundaries where aquaculture and its effects take place. The definition of the relevant boundaries allows the identification of the relevant issues and stakeholders and leads to operational objectives and the development of the implementation plan.

In this review, we start by describing the different steps of the process and then explore in more detail the key issues in aquaculture-fisheries interactions to finally address some of the management measures within an ecosystem approach.

Scoping: defining ecosystem boundaries and the relevant stakeholders

The implementation of an EAA must consider the interactions between aquaculture and all other sectors and users of the watersheds and coastal ecosystems. However, this review will focus only on the interaction between aquaculture and fisheries. The following sections describe the scoping process and some of the aquaculture-fishery issues at each scale.

Ecosystem boundaries and spatial scales

The definition of the relevant ecosystem boundaries is a necessary exercise to identify stakeholders, to address issues and to implement the EAA (Soto *et al.*, 2008). It is also needed to decide whether the planning and implementation of the strategy will cover the whole aquaculture sector of a country or region, or (more typically) will address an aquaculture system or aquaculture area in a country/subregion. In most cases, aquaculture, fisheries and other sectors share an ecosystem with regard to services and space. The most typical scales are: i) the farm, ii) the watershed, waterbody or coastal zone, and iii) the national, regional or global area.

The individual farm is easy to locate and identify, and local effects are often relatively easy to assess. Although it may seem less relevant or meaningful to talk about interactions at this scale, there are cases of large farms negatively affecting fisheries; for example, large shrimp farms built within mangrove areas modify the habitat, which negatively impacts on fisheries and the generation of other ecosystem services, and may also restrict access to local small-scale fisheries. Escapees and diseases originating from a farm can be prevented and/or controlled at the farm scale, although their effects usually occur at the next spatial scale, the watershed, waterbody or coastal zone. Stakeholders are the farmers and workers.

The second scale, that of the watershed, waterbody or coastal zone, includes a cluster of farms that share a common area of water and that need coordinated management. Most relevant aquaculture-fisheries interactions take place at this scale. For example, the eutrophication effect of many small farms on a lake will

affect wild fisheries in that lake by triggering anoxic episodes, thus resulting in fish kills. Clearance of mangrove areas for culture operations may reduce settlement habitat for local fisheries. Stock enhancement usually takes place at this level as well, and the introduced seed and larvae can affect other species and local fisheries. Stakeholders and relevant institutions include: clusters of farms or farmers, individuals involved in postharvest processing and marketing, watershed management bodies, fishers and fisheries institutions and local communities.

The global scale refers to the global industry for certain commodity products (e.g. salmon, shrimp, catfish) and also to global issues such as production, trade of fishmeal and fish oil for feeds, trade of aquaculture products, certification, technological advances, research and education of global relevance. Of particular importance is the world supply of fishmeal as a key ingredient of animal feeds, in particular aquaculture feeds. Most relevant at this scale are the consumers and institutions involved in global trade and global governance.

Identification of issues

Identification of issues where aquaculture affects fisheries can be facilitated by the development of component trees (FAO, 2003) that cover each of the three key areas of EAF and EAA, and these are; human well-being, ecological well-being and ability to achieve (Figure 3). This method also helps to identify issues by structuring the issues into related groups, thus determining their priority and developing management objectives and strategies. The generic trees presented below provide a starting point to help the process of identifying which issues are relevant to the fishery and aquaculture systems being assessed.

Aquaculture is strongly linked to fisheries and affects the latter sector in many ways, both negatively and positively, that can be identified through the production process, inputs/resource use and outputs (Figure 4). Aquaculture

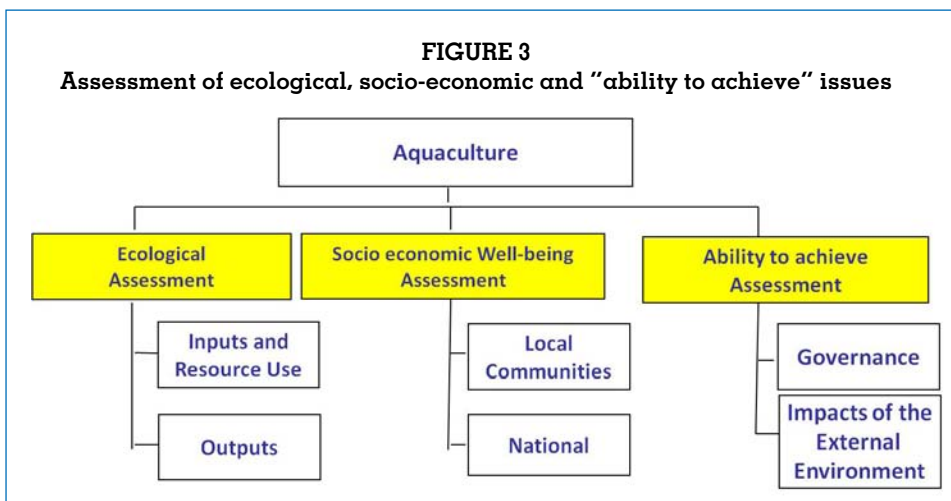
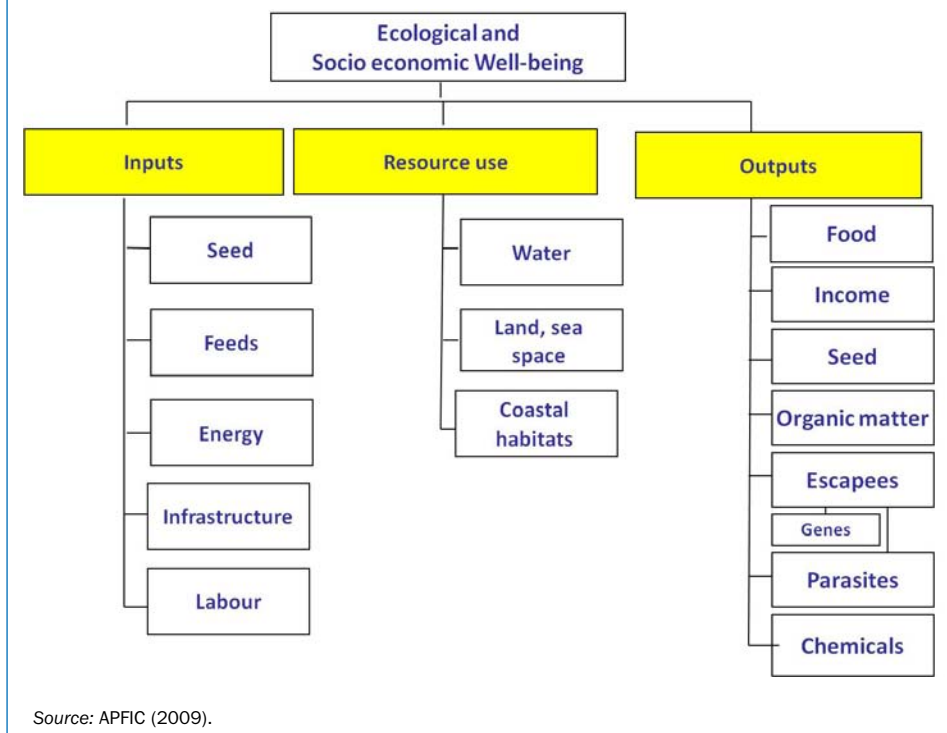


FIGURE 4
Schematic tree to identify issues related with different parts of the aquaculture production process



as a production process requires inputs such as seed and feeds, and requires land, water and coastal space. It produces expected outputs such as biomass, together with unwanted outputs such as excess nutrients, organic matter, chemicals and escapees (Figure 4). Throughout these processes, there are interactions with fisheries. Usually ecological issues (e.g. effects on the resources) have related socio-economic issues (often affecting the fisheries) and ecological and socio-economic issues almost always have a root cause in the governance or ability to achieve.

A further disaggregation of some of the issues related to inputs, resource use and outputs can be seen in Figures 5A and B.

Some governance issues are shown in Figure 6. External drivers should also be considered under “ability to achieve” for example, catastrophic events, climate change, international markets, etc. These can in turn modify the aquaculture effect on the fisheries sector (see Figure 6).

FIGURE 5
Potential effects of aquaculture on fisheries related to inputs (A) and outputs (B). Sign beside indicates negative or positive effect

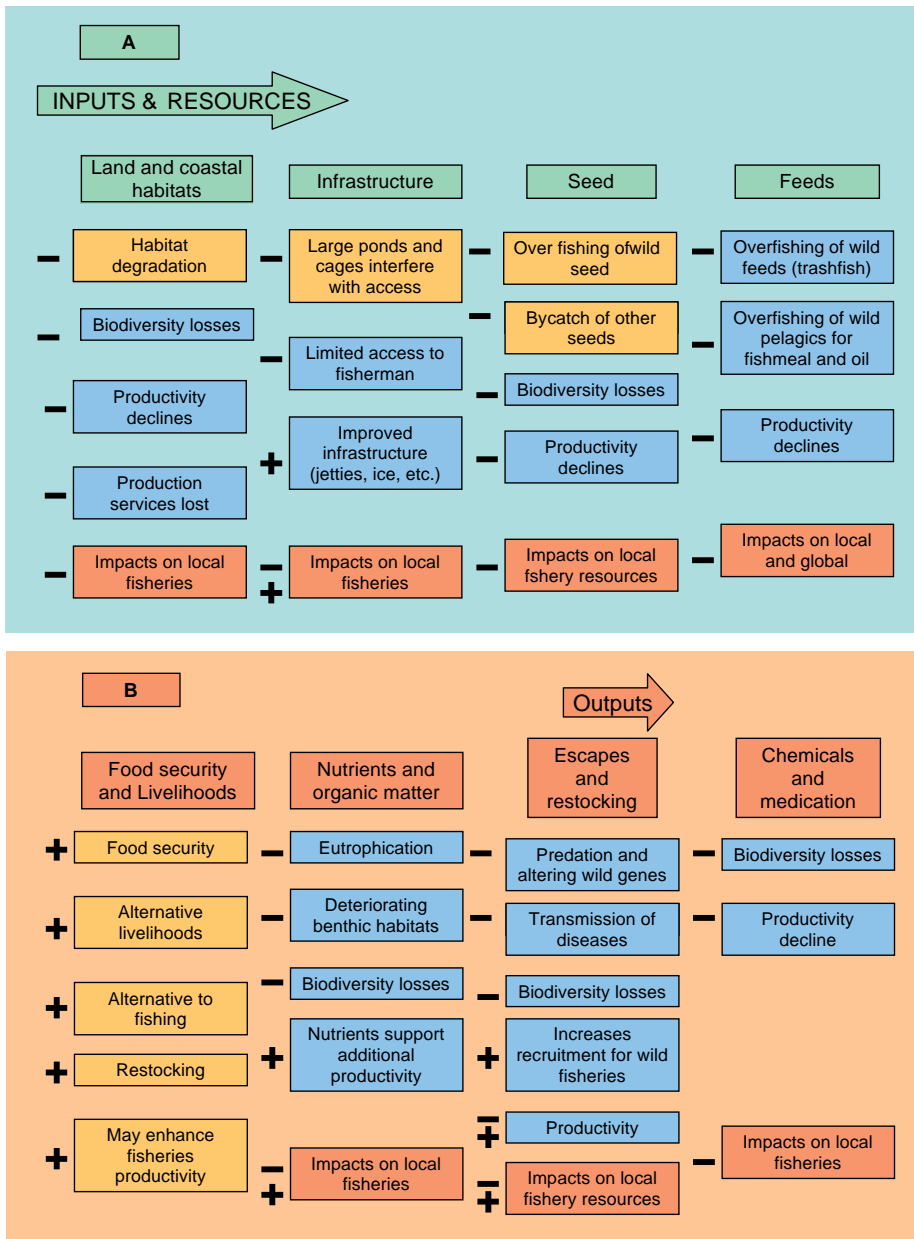
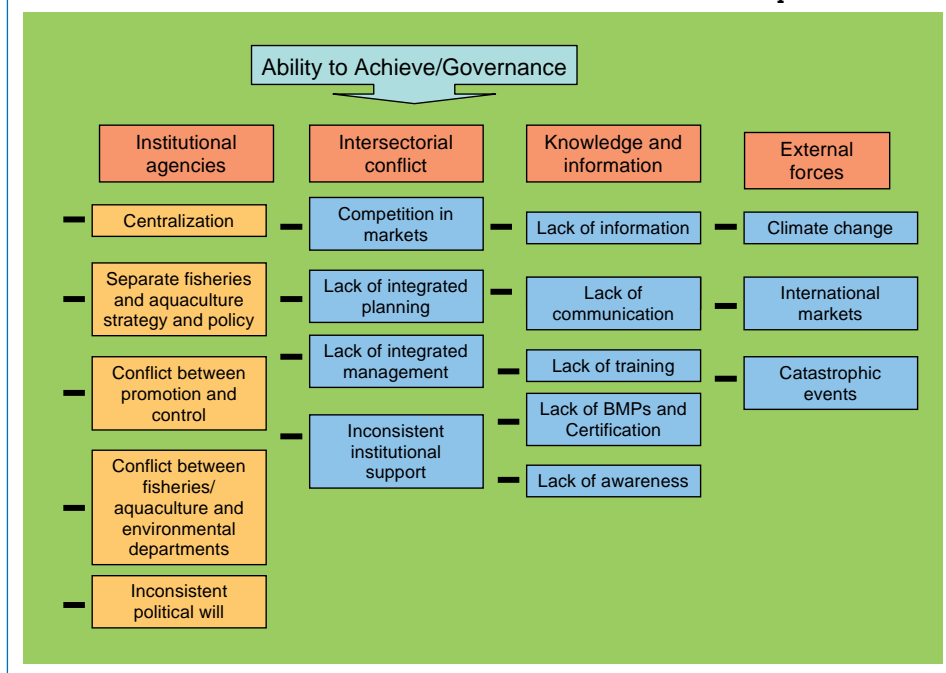


FIGURE 6
Governance issues in the interaction between fisheries and aquaculture



Main issues during the past decade and management measures within EAA

In the following sections, we describe the main interactions between aquaculture and fisheries, focusing mainly on aquaculture's effects on fisheries (issues). We provide examples and case studies and also summary tables where we include potential solutions following an EAA development. Solutions should consist of well-planned management measures that take in account the three guiding principles, that is, the ecological carrying capacity, the social equity and economic benefits and the need to integrate aquaculture with other users of the shared ecosystems and resources. Management measures have to respond to the priorities set by the overarching policy goal and the operational objectives. Diverse management measures are explored in more detail in the sections that follow.

Issues related to resource use and habitat modification by aquaculture

Capture of seed, juveniles and broodstock

Capture-based aquaculture (CBA) is a globally significant activity that can involve the capture of wild individuals, either as broodstock to produce eggs, or as early life stages for on-growing under controlled conditions. These early stages, generically referred to as "seed", vary from eggs to postlarvae through to late-stage juveniles and even small adults. CBA is distinct from hatchery-

based aquaculture (HBA) in that animals are sourced from the wild rather than from hatcheries. CBA is practiced on a diverse range of freshwater and marine species of fish and invertebrates and is a highly significant economic and social activity that has important environmental, including ecosystem, implications. In general, these include over-harvesting of the younger stages of a population, with negative consequences for the sustainability of that population and for related food webs and nutrient cycling (see Box 1).

At least 70 species are included in CBA operations, and these fall mainly into four taxonomic groups: molluscs, crustaceans, echinoderms and finfish. Species involved include such commodities as oysters, bluefin tuna, shrimps, lobster, cod, carps, groupers, seahorses, mussels, crabs, eels, mullets and sea cucumbers (Lovatelli and Holthus, 2008; Sadovy de Mitcheson and Liu, 2008).

This type of aquaculture is practiced on high-value marine finfish species such as tuna which require high protein diets and sturdy culture facilities. However, CBA is also practiced with low-value fish species that are sometimes farmed in small ponds or using inexpensive farming systems with minimum inputs, such is the case of some native freshwater fish in the Amazonian basin (Sadovy de Mitcheson and Liu, 2008). CBA is practiced extensively with bivalves such as mussels that also require minimum inputs and have seed that is generally easily collected.

Although CBA is the oldest type of aquaculture, its current relevance has not been well documented despite the scale of operations involved. FAO, for example, has no database that specifically identifies the global production due to CBA. However, it is estimated that CBA practices provide about 20 percent of the total world marine aquaculture production, while many freshwater species are also cultured, at least in part, from fry caught from the wild (Lovatelli and Holthus, 2008). The reasons for such extensive use of wild animals in culture operations include the inability to raise a wide range of species in hatcheries, supply from hatcheries that does not meet demand or is not of preferred quality, and wild supply that is cheaper or more readily available.

Examples of the different types of CBA include: broodstock collection (e.g. shrimp and groupers), fry collection (e.g. eels, milkfish, shrimp), juvenile collection (e.g. groupers, tuna) and adult collection (e.g. bluefin tuna) to fatten and improve meat quality in short-term holding, as well as for broodstock (Sadovy de Mitcheson and Liu, 2008).

The extent and relative use of wild seed in CBA should decline as the technology for hatchery-produced seed becomes more widespread. Table 1 provides a global expert coarse estimate of the proportion of seed/juveniles obtained from wild or hatchery.

BOX 1. Capture of wild seed: the case of shrimp in Asia and in Latin America

Despite the fast improvements in the hatchery production of postlarvae, shrimp farming in some countries and remote areas still relies on natural seed. Many small-scale shrimp farmers of Latin America continue to use wild-caught postlarvae to stock their production ponds. Also, adult shrimp are routinely captured as broodstock in many parts of the region without having adequate scientific information that supports the level of impact on wild populations. The collection of postlarvae has certainly impacted the wild populations of both the targeted species and the species that are caught incidentally. For example, in Nicaragua, the collection of postlarvae in the wild is claimed to be a major factor responsible for the reduction of shrimp fisheries and other fisheries. Larvae of other crustaceans, fish and other animals of a wide diversity are caught and discarded as bycatch during the shrimp postlarvae collection process, thus affecting non-targeted populations as well. However, wild shrimp postlarvae continue to be utilized because of their apparent hardiness and relatively low price, although the threat of disease is increasingly reducing such a practice. Additionally, it is well known that the use of wild stock, either for breeding or direct culture and their uncontrolled movement by farmers conveys risks of disease and species introductions.

A different situation is being experienced in Asia, which produces about 80 percent of the world's farmed shrimp (*Fishstat plus*, FAO, 2010c). Until the beginning of the current decade, the region relied primarily on the wild-caught *Penaeus monodon* seed and broodstock; however this species is quickly being replaced by the exotic *Litopenaeus vannamei*, introduced from Latin America. Currently the hatcheries in the region produce hundreds of billions of postlarvae per year of this species, and this is considered a big step forward for sustainable aquaculture. Nevertheless, the other 30 percent of farmed Asian shrimp, mostly *P. monodon*, still depends upon wild shrimp populations to provide seed and most of the broodstock requirement. It is just as susceptible to fluctuations in the availability of wild resources as any capture fishery activity. Therefore, the conservation of wild genetic resources is invaluable to shrimp farming.

TABLE 1

Main species groups used in CBA and global estimated* proportion of origin for the seed. (Wild = W; mostly wild (MW = <10% hatchery seed); HH = about half from hatcheries; MH = mostly from hatcheries)

Species group	Larvae obtained from
Bluefin tuna	W
Eels	W
Oysters	MW
Mussels	MW
Lobster	MW
Seahorses	MW
Mullet	MW
Cod	HH
Grouper	HH
Sea cucumber	HH
Shrimp	MH
Tilapia	MH ²
Carps	MH

* Source: FAO fisheries and aquaculture internal database.

The positive and negative issues related to fisheries inputs to aquaculture and possible management solutions addressing negative impacts within an EAA are given in Table 2.

TABLE 2
Issues related to live inputs to aquaculture and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
<ul style="list-style-type: none"> - Mass capture of wild seed, juveniles or broodstock can lead to negative recruitment of wild fisheries (-) - Bycatch of other species along with target species (-) can lead to biodiversity loss, potentially affecting wild fisheries - Destructive fishing practice for collection of wild seed or broodstock (-) can damage fisheries habitat - Capture of wild seed for aquaculture provides livelihoods to thousands of poor fishers and fisheries communities (+) 	<ul style="list-style-type: none"> - EAF management measures - Monitoring and controlling fisheries pressure for seed and fry collection - Definition of quotas and licences for wild seed/ juvenile/subadult and adult collection - Review of fishing methods to reduce bycatch and habitat damage - Provide training and other incentives to use more friendly methods - Provide alternative livelihoods to fishers - Make hatchery seed more readily available and less expensive

Fisheries reduction to fishmeal and fish oil for aquaculture feeds

Fishmeal and fish oil are important protein and energy sources for fish farming feeds. Of the world's total catch of fish, approximately 22 per cent goes to produce fishmeal and fish oil (*Fishstat plus*, FAO, 2010c; Tacon *et al.*, 2011; also see Figure 1). Fishing activities in the Southeast Pacific and Northeast Atlantic are the main sources of the world's production of fishmeal and fish oil. Small pelagic fishes are heavily used as fish feed. These fish are generally the only commercially viable source of long chain omega-3 fatty acids essential to diets for carnivorous farmed fish, such as salmon and tuna, which have high market value and are typically sold in wealthy, developed countries.

Together with aquaculture's rapid development, aquaculture's share of global fishmeal and fish oil consumption has increased. In 2007, the aquaculture sector consumed about 3.8 million tonnes of fishmeal (68.4 percent of total global production) and 0.8 million tonnes of fish oil (81 percent of global production) (Tacon *et al.* 2011).

On the other hand, the ratio of wild fish input via industrial feeds to total farmed fish output has fallen by more than one-third from 1.04 in 1995 to 0.63 in 2007 (Naylor *et al.*, 2009). Such decline underscores the expanding volume of omnivorous fish produced on farms and market pressures to reduce fishmeal and fish oil levels in aquafeeds. Nonetheless, serious challenges remain for lowering the percentage inclusion rate and total quantity of fishmeal and fish oil inputs in feeds and for alleviating pressure on fisheries for aquaculture feed over time. There are also challenges and criticisms to the calculations of fish-in/fish-out ratios (Jackson, 2009) and recommendations to consider efficiency of the reduction in terms of protein, nutrients and energy (Kaushik and Troell, 2010).

One of the main problems is that the scale of this interaction is at the global level, and therefore a challenge and opportunity for EAA is to address the issue with the stakeholders at the local level and with consumers at a broader scale.

Use of low-value fish as feed

Marine finfish aquaculture in Asia has been developing rapidly at around 10 percent per annum, contributed 4 percent of the global finfish production annually over the last decade, and is the fastest growing protein-producing subsector in Asia. However, the subsector is heavily dependent on “trash fish” or “low-value fish”,³ almost always as the only food source of the cultured stocks. It has been estimated that the marine aquaculture sector in China in 2000 consumed about 4 million tonnes of low-value fish (D’Abramo, Mai and Deng, 2002). Demand for trash fish or low-value fish is likely to increase unless viable alternatives are made available and used, and unless the efficacy of use of these feed sources is improved (Edwards, Tuan and Allan, 2004). In the Asian region, one of the fastest growing mariculture commodities is grouper, about six species in all, and in 2005, grouper culture accounted for about 65 000 tonnes and is expected to grow further. The total use of low-value fish by the aquaculture industry in Viet Nam by the year 2013 could be about one million tonnes (De Silva and Hasan, 2007). This is a contentious issue from a resource use view point, reflected in the very high fish to fish conversion rates

The issues related to the use of fish as aquaculture feed and possible management solutions addressing the negative impacts within an EAA are given in Table 3.

TABLE 3
Issues related to the use of fish as aquaculture feed and management solutions within an ecosystem approach to fisheries (EAF) and aquaculture (EAA)

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
<ul style="list-style-type: none"> - Increased pressure on pelagic fisheries resources to provide fishmeal and fish oil (-) - Increased fishing pressure on low-value species for feeding directly to higher-value species (-) - Job and income generation in fishmeal-producing countries (+) - Provides export earnings to fishmeal-producing countries (+) - “Low value” fish taken out of the market chain for hungry and poor (-) - Price of low-value fish rises due to demand from aquaculture, making them less accessible to the poor and hungry (-) - Provides livelihoods for small-scale fishermen and fisheries communities who provide low-value species to cage farmers (+) 	<ul style="list-style-type: none"> - Implement sustainable management of fishmeal/ fish oil/trash fish fisheries (follow EAF) - Monitoring and controlling fisheries - Definition of quotas and licences - Fisheries certification and ecolabeling - Provide alternative livelihoods to fisheries for “feeds” - Perform holistic studies, including on the environmental, social and economic aspects of fisheries and aquaculture and their interaction at local levels, when appropriate - Facilitate access to pelleted feeds - Increase effort to find substitute ingredients - Discourage the culture of top carnivore species and enhance the farming of lower trophic levels (herbivores and omnivorous species)

³ The term “trash fish” is unfortunate because many species involved are in fact species that would be suitable for human consumption if allowed to grow.

Use of common resources (land, water)

There can be spatial interactions between aquaculture and a wild-harvest fishery; both sectors can overlap and compete for port access and use of spatial areas (Hoagland and Powell, 2003). Conflicts are particularly common when aquaculture is introduced into a region where an open-access fishery is established. For example, new cage-culture farms can be placed in areas that were formerly used by fishermen directly for fishing or as passage to fishing areas. In many instances, fishermen and fish farmers may gain access to the aquatic system under different sets of rules and legal rights. Where such disparate property systems are not fully integrated and uses are partially or fully exclusive, conflicts are bound to arise. If property rights are ill-defined or if they are spread across a large number of users, then solutions may be difficult to realize.

The siting of an aquaculture facility, such as a net pen, longline or seafloor grow out, may displace some forms of fishing activity. This occurs when the wild stock is unavailable for harvest because of the failure of fish to migrate in or out of an area allocated to farms or because fishermen no longer have access to their fishing area. As more space is allocated for aquaculture, there may be both a smaller stock available for fishing and more congestion in the areas remaining open for wild harvest. These effects could lead to an increase in the cost of fishing. On the other hand, as more area is allocated for wild harvest, the cost of aquaculture might increase if the potential for achieving economies of scale is constrained. In some cases, the access of local fishermen to their resource is also restricted by aquaculture facilities due to the potential for robbery and vandalism. Some examples are provided in Box 2.

BOX 2. Examples of conflicts and synergies between fisheries and aquaculture using common coastal areas

In Chile, there are often conflicts between salmon farms and artisanal fishers for the use of coastal marine areas or access to these (Soto, Jara and Moreno, 2001). Often, salmon farms do not allow the latter to approach farms due to fear of robbery or vandalism to cages, while the fishermen complain that the farms are not allowing them to reach their traditional fishing grounds. A similar case can be described for shrimp farming areas in the Gulf of Fonseca, Nicaragua, where armed guards often keep fishermen away from large farms, not allowing access to their former and potential fishing channels and lagoons within the mangrove.

On the other hand, in some communities of the Asia-Pacific region, coastal artisanal fishers' livelihoods and sustenance depend on the coastal cage-culture farmers, who provide, almost on a daily basis, the only source of income, by providing trash fish to feed cultured stocks of high-value marine species such as groupers. The artisanal fishers may operate a variety of gear types, including large, stationary, semi-mechanically operated lift nets; gillnets; cast nets and weirs, and they can coexist well with aquaculture. This complementarity and livelihood interdependence has been ongoing for decades, without any one group being disadvantaged, and most of all, without apparent harmful impacts on the stocks.

Aquaculture modification of physical habitat

Some aquaculture structures have been likened to fish aggregation devices (FADs) (Dempster *et al.*, 2004), in that they provide substantial submerged structures that attract numerous fish species (Dempster *et al.*, 2002, 2005, 2010). However, unlike traditional FADs, sea-cage fish farms and shellfish longlines, racks and trays may also affect (both positively and negatively) the availability of food (i.e. through wastes and uneaten feed, and by providing substrate where organisms can grow and can be eaten) to wild fauna in their surrounding areas and therefore affect fisheries (Fernandez-Jover *et al.*, 2011).

Aquaculture practices have had extensive influence on some habitats. For example, pioneering shrimp farms negatively impacted mangrove forests in tropical countries. Building of ponds and modification of waterflows and hydrological regimes of tropical estuaries for aquaculture systems can have an impact on the life cycle and productivity of local fisheries depending on those habitats. Fish farms are common artificial elements in coastal ecosystems in cold temperate to tropical regions; cages are used for growing fish, while seaweeds, mussels, oysters and clams are grown on suspended ropes, racks or trays. These structures can occupy substantial coastal space. However, it is difficult to separate the effects caused by the structure from those derived from increased nutrient availability and food in general.

Aquaculture structures may therefore affect the presence, abundance, residence times and diets of fish in a given area and can, therefore, have important effects on fisheries. Aggregations of wild fish form around sea-cage fish farms, regardless of the cultured species they contain (e.g. salmonids, seabream, European seabass), wherever they occur in Europe (e.g. the Mediterranean Sea; (Dempster *et al.*, 2002, Fernandez-Jover *et al.*, 2011), the Canary Islands (Tuya *et al.*, 2006); and Norway (Dempster *et al.*, 2005)). Such aggregations of fish species that are typically targets of fisheries (e.g. carangids, mugilids and sparids in the Mediterranean, and gadoids in Scotland and Norway) in a concentrated area may affect local fisheries in several ways, including redistribution of stocks and aggregation of stocks, thereby increasing catch per unit effort (Box 3). In addition to sea-cage farms, fish aggregations have also been described around bivalve aquaculture rafts and longline installations (Laffargue, Bégout and Lagardère, 2006).

Cage farms in inland waters also serve as aggregating devices. This is particularly true for tilapia and pacu (*Piaractus mesopotamicus*) cultured in cages in Brazil, Colombia and Mexico, as well as rainbow trout (*Oncorhynchus mykiss*) cultured in Scottish lochs and salmon and trout cultured in Chilean lakes. In all cases, both wild fish and escapees congregate around the cages to feed on uneaten feed and organic wastes. Soto and Jara (2007) showed that native fish biomass and productivity can increase by up to four times near cages in oligotrophic lakes, and that the abundance of wild trout can increase by up to

10 times (see Box 3). Such increases in biomass and productivity are very often used by local recreational fisheries.

BOX 3. Examples of fish cages attracting and increasing wild fish and fishery productivity

In general fish-farming cages increase local fish abundance and often productivity through direct consumption of wasted pellet feeds and through increased local productivity. In Lake Llanquihue, southern Chile, bays with salmon farming have higher recreational fishing yield for trout and salmon, and fishermen often go near to the cages to fish. Occasionally the abundance of wild salmon and trout promotes fishing with gillnets by local fishermen, even though such practice is forbidden by law, as only recreational fisheries are possible in these lakes.

The table below shows the average values for freshwater fish biomass and productivity in Lake Llanquihue bays with salmon farms (N=4) and in control sites (bays without salmon farms; N=3). Biomass and productivity were evaluated by gill netting and echosounding (adapted from Soto and Jara 2007).

Wild fish	Bays	Biomass (kg/ha)	Productivity (kg/ha/year)
Salmon and trout*	With salmon farms	32.8	16.6
	Control sites	1.9	0.8
Native species**	With salmon farms	11.1	5.1
	Control sites	3.2	1.4

* Rainbow trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*) and Atlantic salmon (*Salmo salar*).

** Silversides (*Odontesthes mauleanum* and *Basilichthys australis*) creole perch (*Percichthys trucha*) and large whitebait (*Galaxias platei*).

Arechavala-Lopez *et al.* (2010) demonstrated that coastal aquaculture and local fisheries can be directly connected. They showed that wild bogue (*Boops boops*) that typically aggregate at fish farms form a significant component of the catch of local fisheries. Using the body fatty acid composition as a biomarker of pellet feeding, they traced fish that were resident around farms and consumed sufficient amounts of farm waste feed to modify their condition and fatty acid profiles as compared to those captured by a fishery that operated several kilometers distant from farms. Also, the farms significantly concentrated higher bogue biomass. In this case, fisheries at a local scale appear to benefit from a biomass export from fish farms.

Aquaculture structures also influence settlement processes for certain wild fish populations, although the overall importance of this to recruitment to populations is unknown. Information on the role of fish farms as settlement habitat is scarce. For Mediterranean fish farms, Fernandez-Jover *et al.*, (2007a,b) found that 20 juvenile fish species settle at farms throughout the year. The influence of fish cages on the pelagic postlarval stage could affect the connectivity between recruits and fishing stocks, through a spatial modification of the available settlement habitat, alteration of mortality and modification of trophic resources (e.g. increase of particulate organic matter or zooplankton abundance). Bivalve aquaculture structures also affect fish settlement. Algal and epibiotic growth on the bottom mesh used in bivalve aquaculture (as practiced in North Carolina and elsewhere) can enhance the nursery habitat for the many species that preferentially associate with seagrass habitat, at least as juveniles (Powers *et al.*, 2007).

The effects of farms on fisheries described above usually take place at the waterbody scale as an aggregated result from several or clusters of fish farms. Up to 170 species of wild fish have been documented to associate with fish farms as adults or juveniles worldwide (Sanchez-Jerez *et al.*, 2008). Yet the overall effect on the associated fisheries yield (both food fisheries and recreational fisheries) has not been properly assessed at a wide scale.

The positive and negative issues related to habitat modifications and possible management solutions addressing the negative impacts within an EAA are given in Table 4.

TABLE 4
Issues related to habitat modifications and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative impacts
<ul style="list-style-type: none"> - Excessive finfish cage culture could result in the destruction of benthic habitat where fishery resources can otherwise develop or be dependent on (-) - Aquaculture can reduce access to the traditional fishing areas by local fishermen (-) - Transformation of natural coastal fishery habitats into fish ponds (-) - Fed aquaculture can provide additional nutrients, therefore in some cases supporting additional fisheries (+) - Fish cages can act as fish-aggregating devices, providing shelter to wild fish and potentially enhancing fisheries (+) 	<ul style="list-style-type: none"> - Improve site selection for cages, avoiding sensitive habitats (wetlands, mangroves, etc.) and areas currently used by fisheries or as pathways to fisheries - Set production limits considering environmental carrying capacity - Develop integrated coastal zone management plans allocating aquaculture and fisheries access to optimize wild harvest and aquaculture production - Encourage “enhanced fisheries” and improved aquaculture-fisheries coupling by appropriate aquaculture site selection and planning, including stakeholder participation (specifically fisheries)

Issues related to aquaculture outputs

The following aquaculture outputs and related effects on fisheries are considered in this section: food production (most biomass resulting from aquaculture); production of seed for CBF; escapees and species introductions; release of nutrients, diseases, medications and chemicals; income, market and trade and impacts on fisheries will be also addressed.

Food production

Aquaculture provision of food fish can complement and supplement that provided by fisheries. Aquaculture can increase availability of good-quality food and has increased the awareness and consumption of fish products worldwide. In some cases, aquaculture can ease the pressure on wild fish stocks when fisheries delivery fails or is of less quantity or poorer quality. As an example, in the Amazon basin and other watersheds like those of the Orinoco and the Essequibo rivers, fish derived from aquaculture are available when the river is high and the fishery catches are low. The downside is that the aquaculture prices are low when the river is full and the fishery delivery is plentiful (Wiefelds pers. Obs.). Aquaculture production also has had an important impact on food quality and food safety when producing for export. These changes have also improved the fishery products, especially in the processing plants and through the market chain.

Seeds for culture-based fisheries and stock enhancement

Culture-based fisheries (CBF) is the provision of aquaculture-produced larvae or juveniles to supplement and improve the recruitment of one or more aquatic species and therefore raising the total production or the production of selected elements of a fishery beyond a level which is possible through natural processes. Cultured-based stock enhancement particularly emphasizes the releasing of seed produced in aquaculture installations, in addition to other enhancement measures such as improvement of habitat. The latter is often done to protect an endangered aquatic animal species whose population can not be sustained due to failure in key biological links such as reproduction and early stage development due to environmental change or human factors. Sea ranching, considered as another form of CBF, is the release of cultured juveniles into unenclosed marine and estuarine environments for harvest at a larger size in “put, grow and take” operations (Leber *et al.*, 2004).

CBF and stock enhancement takes place either in artificial waterbodies (e.g. dam lakes) where there may be no impact on natural populations, or in natural ecosystems such as lakes, lagoons and coastal marine areas, where environmental concerns include potential effects on the native fauna and the ecosystem in general.

The increasing capacity for massive production of seed in hatcheries has led to the growing and strengthening of CBF and stock enhancement programmes worldwide. These are becoming the major contributions of aquaculture to enhance fisheries in many parts of the world.

The potential of CBF was recognized long ago as a cost-effective means of increasing the food fish supplies in rural areas (Fernando and Ellepola, 1969; Mendis, 1977). However, the practice gained momentum more recently due to the increasing demand for fish, improvements in seed stock production and availability, and also as a major strategy by governments to increase food fish production and livelihoods, particularly in rural impoverished communities (Amarasinghe and Nguyen, 2009). In many instances, it is also seen as an environmentally minimally perturbing practice and a good example of multiple, effective use of water resources (De Silva, 2003).

Relevant marine stock enhancement activities have been taking place in many countries since early 1900, involving finfish, crustaceans and shellfish; therefore, enhanced stock and ocean ranching are increasingly contributing to marine capture fish production (Leber *et al.* 2004; Bartley and Leber, 2004). Li *et al.* (2009) recently reported that 94 countries are implementing different types of aquaculture-based fisheries involving some 180 species of aquatic animals globally. For instance, China’s stock enhancement releasing programme involved over 100 species of aquatic animals with a total of 19.7 billion fingerlings/fry/fertilized eggs released to the sea, inland lakes, reservoirs and rivers in 2008

(Shi, 2009). It was reported that the Korean Government allocated a budget of USD\$33.7 million for ocean ranching projects during 2002–2011 in the Yellow Sea, which involves target species such as of olive flounder (*Paralichthys olivaceus*), black rockfish (*Sebastes schlegeli Hilgendorf*), flat greenling (*Hexagrammos* spp), Chinese shrimp (*Fenneropenaeus chinensis*), blue crab (*Scylla serrata*) and Manila clam (*Ruditapes philippinarum*). In China, it is estimated that such resource enhancement activities contributed to a catch increase of 120 000 tonnes, valued at USD 225 million in 2008. The cost/benefit ratio of resource enhancement is around 1:5. In other words, it profited 1.5 million professional fishers by USD150 per capita in China. The large-scale jellyfish releasing programme carried out in China's Liaoning Province significantly increased the catch of jellyfish, with the catch volume reaching 23 500 tonnes in 2009, which would profit the 130 000 fishers by nearly USD150 per capita (Liu, 2009).

Japan, which has a long history of marine ranching (FAO, 1999), also pioneered the use of the open seas for CBF. In this country, catch of released flounder reached 30–90 tonnes and comprised 4.6–20.1 percent of the landed weight and 3.5–14.8 percent of the landed value from 1996 to 2005. Recapture rates of released fish were 7.2–17.0 percent for 1996–2002 year-classes (Tomiyama, Watanabe and Fujita 2008).

Other countries active in inland and marine stock enhancement include Australia, China, Denmark, France, Iceland, Iran, Korea, Norway, Spain, Thailand, the United Kingdom and the United States of America; and many island nations of Oceania have active programmes for restocking their indigenous populations of molluscs, such as giant clams, pearl oysters and snails.

In tropical developing countries, where the production of more fish for food is the goal of most fisheries activity, high-yielding herbivores, detritivores and planktivores (like tilapia and carp) are commonly stocked in lakes and reservoirs, specially in Asia (De Silva, 2003).

Within Latin America, the largest CBF efforts have involved exotic species. In Mexico, CBF of tilapia in lakes and impoundments is the most extensive enhancement programme. In 2007, this kind of production accounted for 96 percent of the total tilapia production in the country (66 000 tonnes in 2007). The tilapia fry production to sustain the CBF is mostly produced by government hatcheries. In Cuba, there have been important CBF efforts with common carp (*Cyprinus carpio*), North African catfish (*Clarias gariepinus*) and tilapia. Many artificial lakes have been seeded with seed produced in government hatcheries. In Brazil, enhancement programmes are a strategy to preserve endemic species that have been subject to overfishing and to other anthropogenic impacts. This is the case with the pacu, a migratory species of the Paraná River basin in Paraguay and Uruguay, whose populations are being progressively reduced. This species is highly valued commercially and socially.

The Chilean Government has promoted and assisted the release of fingerlings of rainbow and brown trout (*Salmo trutta*) in natural lakes and river systems since the late 1800s as an effort to develop recreational fisheries for these exotic species (Soto *et al.*, 2007). The seeding of some waterbodies continues in an attempt to provide good recreational fisheries opportunities, as trout and salmon are the only species legally available for such fisheries. Currently, recreational fisheries based on exotic trout and salmon are important sources of income and employment, not only in southern Chile but also in Argentina.

Ecological impacts of the salmon and trout introduced for recreational fishery purposes (and also as escapees from aquaculture) have been well described in several countries (McDowell 2003; Soto *et al.*, 2007; Pascual *et al.*, 2007). However, for most species used (both native and exotic) in CBF worldwide, long-term impacts of such practices on biodiversity and structure and function of ecosystems have not been thoroughly examined, and this remains an important shortcoming of CBF.

Limited assessment efforts are often focused on the biological results of the release, for example, recapture rate and impact on fisheries (e.g. contribution of released seed to catch), while little is known on the economic efficiency and ecological impacts (Leber *et al.*, 2004) (Box 4). For example, tilapia has been

BOX 4. Impacts of badly planned CBF due to modifications to the ecosystem structure and function

The major risks include the following:

- i) poor performance of enhanced species, such as slow growth and small size caused by increased intraspecific competition for food and habitat due to larger densities by the addition of hatchery-reared fishes;
- ii) possible structural changes in the aquatic community and ecosystem due to shifting prey-predator relationships and competition between hatchery-reared fish and individuals of the same species and other species with similar ecological requirements;
- iii) transmission of pathogenic organisms when health is not managed in the production of fish seed used for release; and
- iv) environmental modifications to natural habitats and breeding areas for fishery resources due to activities of introduced species (e.g. building of nests by tilapia).

Competition (inter and intraspecific) may lead to a reduction in abundances of competing species and prey species or even local extinctions due to increase in the abundance of released fish (Molony *et al.*, 2003). Stock enhancement of certain fish species may cause adverse impacts on ecosystem functioning. For example, the grass carp (*Ctenopharyngodon idella*) release programme in East Lake, Wuhan, China caused significant damage to aquatic weeds in the lake which were absorbing nutrients and contributed to the deterioration of the water quality in the lake. Uncontrolled release of zooplankton-feeding fish may contribute to algal over-bloom and eutrophication of the waterbody. If health management is not adequate, there is great risk of introduction of diseases and parasites to the wild population owing to the low resistance of the wild population and difficulty of disease control in natural waterbodies.

BOX 5. Case examples of CBF positive impacts in Mexico

In Mexico, there is a CBF programme for the pike silverside (*Chirostoma estor*) fishery in Lake Patzcuaro, based on recent technological breakthroughs in the research of its intensive larval rearing (Ross, Martinez Palacios and Morales, 2008). The fishery for this species in Lake Patzcuaro is a source of income generation for almost 2 000 families, but has been steadily declining over the last decade due to uncontrolled exploitation. Current efforts by federal and state governments seek to establish a comprehensive CBF programme in which the technological element (fry production) is only one element, complemented with stakeholders' involvement and participatory approaches.

Another case is that of a native cichlid, the Mexican mojarra (*Cichlasoma urophthalmum*) in lagoons in the southern Mexican State of Tabasco. The private company Puctesa produces the fingerlings that, through CBF programmes of the State of Tabasco, are stocked in waterbodies of diverse size to sustain traditional small-scale fisheries in rural communities. Beginning in 2002, annual productions of at least 2 million fry have been stocked, with peaks in 2005 and 2006 of 12.5 million fry. As of 2005, an estimated 4 000 families had benefited from this programme.

used extensively for CBF in Asia, Latin America (see Box 5) and Africa, yet the potential negative impacts have been scarcely assessed. Canonico *et al.* (2005) suggested that tilapia introductions in aquatic ecosystems can have relevant negative effects on local biodiversity, while De Silva *et al.* (2004) suggested that tilapia would tend to invade those habitats that have been degraded from various anthropogenic impacts, and made unsuitable for indigenous species.

The positive and negative issues related to CBF and possible management solutions addressing the negative impacts within an EAA are given in Table 5.

TABLE 5
Issues related to CFB and stock enhancement impacting fisheries and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative impacts
<ul style="list-style-type: none"> - Stocking and CBF may affect wild populations through the transmission of diseases, increased competition, predation, modification of habitats and disruption of the structure and function of aquatic ecosystems (-) - Negative genetic impacts including interbreeding between hatchery-originated individuals and wild populations pose short-term hazards for the fitness and productivity of the wild fish which might be reduced by outbreeding depression, giving a loss of local adaptation and in the long term, genetic variability between natural populations might be reduced - Aquaculture-based stock enhancement programmes can significantly contribute to capture fisheries (+) - CBF brings about significant positive impacts on livelihoods and food fish supplies of rural communities in many countries world-wide (+) - Responsible aquaculture-based stock enhancement contributes to the conservation and improvement of certain fisheries through enhancement of endangered species (+) 	<ul style="list-style-type: none"> - Promote risk assessment and monitoring of CBF and restocking programmes - Follow national regulations and international guidelines for the introduction and movement of non-native species/strains to the wild and for culture (FAO, 1995; ICES, 2005) - Select native broodstock for the production of eggs and juvenile releases (genetic profile of broodstocks) - Create a database for origin and genetic diversity of cultured stocks - Assess the genetic diversity of cultured stocks - Promote stock identification and differentiate stocked from wild fish

Aquaculture escapees and their impacts on fisheries

Escapes of juvenile or adult fish are a constant possibility if operational or technical failures occur at fish farms. A single fish farm may hold hundreds of thousands to millions of cultured fish. In the Mediterranean Sea, approximately 500 million seabass and 450 million seabream are held in sea cages, with wild stock numbers believed to be considerably lower (ICES, 2006). Similarly, over 300 million Atlantic salmon are held in sea-cages in Norway at any given time (Norwegian Fisheries Directorate, 2009), far outnumbering the approximately 1 million salmon that return to Norwegian rivers from the ocean each year to spawn. In 2008, in Chile, the total production of salmonid species was 500 000 tonnes (*Fishstat plus*, FAO, 2010c); that means there were about 180 million salmon (mostly Atlantic salmon) in sea cages in the southern fjords, where salmonids are not native.

In some cases, due to the large numerical imbalances of caged compared to wild populations, escape raises important concerns of ecological and genetic impacts. Such impacts are very similar to those described in the case of stock enhancement and CBF.

The evidence of ecological effects of escapees on wild populations is largely limited to salmonids, as these interactions have been well documented, with more limited and general information for other species such as tilapia (De Silva *et al.*, 2004; Canonico *et al.*, 2005). The potential ecological risks from escaped farmed fish to fisheries are similar to those described in the case of stocking, that is, they may affect wild populations through the transmission of diseases, increased competition and predation, and genetic interactions. Farmed fish can interbreed with wild fish stocks. In this way, the new generation of wild fish, whose traits have developed over thousands of years of evolution, will be genetically mixed with genes from a more uniform farmed stock. In the long run, this may change the wild stock to the extent that it no longer will be able to survive in its original environment. Some interspecific hybridization might also occur should farmed fish escape into an ecosystem where there are very closely related species. Escaped fish can compete for mates or nesting sites. In Norway, escaped farmed fish have been observed digging up and destroying established wild salmon spawning beds.

Farmed fish can escape directly from net-pens and other enclosures due to human error, damage from catastrophic natural events such as severe storms, or following damage to structures by predatory marine mammals. This is well illustrated for salmon (Box 6). Some species of finfish and shellfish that spawn freely in captivity and produce pelagic eggs may release fertilized gametes into the surrounding environment. All these possible risks are believed to pose a greater threat to natural populations (conspecifics of the escapees) than to other fish populations at large.

BOX 6. Escape of farmed salmon in Norway

The main proportion of escaped salmon in Norway is the result of strong weather forces. The Norwegian coastline is rough, and those who want to engage in farming activities must ensure that their facilities can withstand the occasional storm.

The categories “farm failure”, “propeller damage”, “handling” and “failure in smolt farm” comprise of 65 percent of the number of escaped fish in salmon farming. For these four categories, most of the responsibility lies with the farmer and or provider of equipment and services such as transport (wellboats), hatchery, etc. Escapes as a result of storms are included in the “farm failure” category. Storms cannot be blamed on the farmer, but the farmer is responsible for making sure that his/her farms can withstand normal weather conditions, including storms.



The unintentional or accidental release of cultured organisms from culture farms into the wild is enhanced by factors such as the continuity of aquatic ecosystems, the number of operating farms and the high mobility of many farmed aquatic species.

The number of farmed salmon escaping to the wild is large relative to the abundance of their wild conspecifics (Thorstad *et al.*, 2008). The most relevant effect seems to be outbreeding depression of wild conspecifics. Escaped farmed salmon are clearly an international issue, with frequent observation of their crossing national borders.

Escapees can eventually establish self-sustained populations as introduced species or alien species (Box 7). Impacts of introduced species fall into two broad categories: ecological impacts, which include biological and genetic effects, and socio-economic impacts. However, these two categories are not independent, and socio-economic changes to fisheries brought about by alien species can in turn cause more ecological changes. Thus, a reduction in native species may be from direct interaction with an exotic species, or it may result from increased fishing pressure or changes in land use brought about by the presence of a newly established species.

However aquaculture production based on alien species could have indirect positive effects on fisheries; for example, the introduction of the whiteleg shrimp (*Litopenaeus vannamei*) into Asia for aquaculture development has significantly reduced the pressure on native giant tiger shrimp (*Penaeus monodon*) larvae and wild broodstock, and therefore it is possible that more shrimp stock could be available to higher-value fisheries.

BOX 7. Reproductive success of escapees

Escaped salmon do not appear to greatly benefit local fisheries in Europe, other than through short-term captures after escape incidents; however, escapees may support local fisheries to an extent in certain conditions. Deliberately released gilthead seabream (*Sparus aurata*) in the Mediterranean Sea were able to adjust to a natural diet and subsequently grew well, indicating they adapted to life in the wild and likely added to local population numbers (Sánchez-Lamadrid, 2004). In addition, while small-scale escape events are relatively frequent, very few escaped seabream or seabass occur near the sea-cages from which they escaped (Dempster *et al.*, 2002), which suggests that escapees move away from farms to other more favourable habitats, or that they are fished by sport and professional fisheries. Similarly, recaptures of Atlantic cod (*Gadus morhua*) escapees in local commercial and recreational fisheries in Norway are high (approximately 40 percent; Uglem *et al.*, 2008), indicating that local fisheries receive temporary increases after escape events.

Escapes of chinook salmon (*Oncorhynchus tshawytscha*) in southern Chile have generated a successful population of this species running up rivers both in Chile and Argentina and being actively used for recreational fisheries (Soto *et al.*, 2007). However major escapes of Atlantic salmon in this country do not seem to have generated successful reproductive populations (Thorstad *et al.*, 2008).

The positive and negative issues related to aquaculture escapees and introductions and possible management solutions addressing the negative impacts within an EAA are given in Table 6.

TABLE 6

Issues related to aquaculture escapees and introductions and possible management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
<ul style="list-style-type: none"> - Escape fish may affect wild populations through the transmission of diseases, increased competition, predation, modification of habitats and disruption of the structure and function of aquatic ecosystems (-) - When escaped fish have conspecifics in the area, interbreeding between hatchery-originated individuals and wild populations poses a short-term hazard for the fitness and productivity of the wild fish, which might be reduced by outbreeding depression, giving a loss of local adaptation and in the long term, genetic variability between natural populations might be reduced - In some instances, escapes can increase catches in local fisheries (e.g. salmon artisanal and recreational fisheries in Chile) (+) 	<ul style="list-style-type: none"> - Ensure containment measures for cage farming (e.g. quality, design and strength of nets for cages; encourage the use of anti-predator nets) - Ensure aquaculture breeding programmes do not lead to inbreeding - Encourage containment measures for land-based water effluents (e.g. use of nets, trap cages) - Site aquaculture away from wild fish migratory routes - Devise mitigation measures such as capturing the escapees, encouraging a short-term fishery if appropriate and legally feasible

Interactions and impacts resulting from release of organic and inorganic nutrients

Whether a nutrient becomes a pollutant in an aquatic system is a function of whether it is a limiting nutrient in a given environment, its concentration, and the carrying capacity of that ecosystem. In fresh waters, phosphorus is typically the limiting nutrient (Hudson, Taylor and Schindler, 2000), so its addition will

dictate the amount of primary production (algal growth). In marine environments, nitrogen is typically the limiting nutrient (Howarth and Marino, 2003), so its addition will do likewise.

Soluble nutrients coming from the digestion processes of farmed aquatic animals will dissolve in the water column, and their initial dilution and transport is a function of water current dynamics. Solid waste made up of uneaten feed pellets, feed fines (fine particulates caused by pellet damage during transport or automatic feeding systems) and faecal material can also accumulate below culture cages and in the outflows of aquaculture facilities. The accumulation will also depend on the local currents and depth.

Since nitrogen and phosphorus are released from fish cages and fish or shrimp ponds, there is always the potential for fish culture to promote eutrophic conditions, either by supplying a readily available nutrient source directly to phytoplankton or by oxygen removal, accompanied by nutrient release and via the decomposition of waste solids. High nutrient concentrations can also trigger algal blooms which reduce water clarity (and consequently sunlight availability in the water column to other organisms), and can strip oxygen from the water column when the organisms die, sink and decompose (Gowen, 1994).

Eutrophication, low oxygen events and fish kills affecting local fisheries are common events in some lakes and reservoirs in Asia where there is a high density of small-scale fish-cage farms that together produce excess nutrients in dissolved and particulate form and therefore exceed the carrying capacity of the waterbody (e.g. in Indonesia; Abery *et al.*, 2005).

Organic enrichment of the seabed is the most widely known effect of fish farming globally. Such effects have been reported from various parts of the world, including Scotland (Gowen, Bradbury and Brown, 1985), the east coast of Canada (Hargrave *et al.*, 1993), the Northeastern Pacific (Weston, 1990), Chile (Soto and Norambuena, 2004) and the Mediterranean (Karakassis *et al.*, 2000; Karakassis, Pitta and Krom, 2005). This can impact benthic (e.g. seagrasses) and other sensitive habitats (e.g. corals) close to the farm (Holmer *et al.*, 2008). These areas are often very important as food sources or habitats for local wild fisheries.

However, in many cases, additional nutrients can also provide more food and enhance local fisheries (Boxes 8 and 9). This potential positive effect, i.e. stimulation of growth of some fish species, needs to be weighted against possible impacts on ecosystem structures and functions that may lead to changes in species populations being targeted by the fishing industry.

The positive and negative issues related to organic and inorganic output by aquaculture and possible management solutions addressing the negative impacts within an EAA are given in Table 7.

BOX 8. Aggregation of wild fish beneath fish cages due to feed availability

The interaction of farmed and wild fish in the Mediterranean has been addressed by various authors during the past years. McDougall and Black (1999) reporting data from the Mediterranean and Angel, Krost and Gordin, (1995) from the Gulf of Aqaba have attributed the relatively low impacts of organic enrichment on the seabed to the consumption of the organic matter by demersal fish and invertebrates. Underwater diving and video surveys beneath fish farms in the western and eastern Mediterranean (Dempster *et al.*, 2002; Vega Fernandez *et al.*, 2003; Golani 2003) confirmed that large numbers of fish of various species were aggregated under the fish cages during feed supply. This aggregation of wild fish has been shown to be related to the feed supply rather than to a fish aggregating device (FAD) effect (Tuya *et al.*, 2006), and their densities approach “normal” densities after the cessation of fish farming. Dempster *et al.* (2002) have shown that the abundance, biomass and species richness of the aggregating fish assemblages are negatively correlated to distance from shore and positively correlated with the size of the farm. These authors suggest that coastal cage fish farms may act as small pelagic marine protected areas (MPAs), although in a later paper (Dempster *et al.*, 2004), they also emphasized the potential effects of such large aggregations, including increased vulnerability to fishing and pathogen transfer between caged and wild fish. Vita *et al.* (2004) conducted field experiments with sediment traps and concluded that 80 percent of the particulate organic matter leaving the rearing net-pens may be consumed before settling on the seabed, and they have attributed a large part of this consumption to the wild fish aggregating beneath the farms. On the other hand, Dempster *et al.* (2005) have shown that there are differences between aggregations in the Mediterranean and other sites regarding the vertical variability of the wild fish assemblages, thereby concluding that there is some uncertainty in modelling nutrient dispersal prior to the installation of fish cages.

BOX 9. Increasing fishery productivity

Aquaculture can especially increase fishery productivity through additional nutrient and feed outputs (e.g. from cages) in oligotrophic ecosystems, and provision of refuge (e.g. fish cages, mussel rafts) in most environments. In the oligotrophic Mediterranean Sea, cage aquaculture is responsible for less than 5 percent of the anthropogenic input of nutrients (Karakassis, Pitta and Krom, 2005). However, farms are typically clustered in specific regions, thus their influence in regional nutrient budgets may be significantly higher. Machias *et al.* (2005, 2006) suggest that nutrients originating from sea-cage aquaculture in Greece have resulted in increased primary productivity in specific regions and led to increases in wild fish populations and a doubling of fisheries landings in regions with fish farms as opposed to regions without fish farms. In Spain, increased commercial and recreational fishing around fish farms has been reported. Farm-associated fish have been identified in samples from local fish markets through their distinct farm-modified fatty acid profiles (Fernandez-Jover *et al.*, 2007a; Arechavala *et al.*, 2010). In Norway, local fishermen report relatively high amounts of saithe (*Pollachius virens*) with salmon pellets in their stomach. In general, farm-associated saithe are significantly fatter and have much larger livers than non-associated fish (Dempster *et al.*, 2011). Previous studies have also shown that saithe caught, tagged and released at a salmon farm later occurred in the catches of commercial fishermen (Bjordal and Skar, 1992). In this regard, most of the aggregated species can be considered as “type B” (species attracted to artificial reefs but also taking some production benefit from the

BOX 9. (Continued)

reef), following the model proposed by Bortone (2007), because of the use of feeding resources provided by the artificial habitat and lost food pellets. Therefore, marine farms can provide one of the functions of marine protected areas (Forcada *et al.*, 2009), by increasing the export of fish biomass. If restrictions on fishing are applied within farm leasehold areas, it has been suggested that coastal sea-cage fish farms may act as small (up to 160 000 m²) pelagic marine protected areas (Dempster *et al.*, 2002, 2006; Soto and Jara, 2007).

TABLE 7

Issues related to organic and inorganic nutrient output by aquaculture impacting fisheries and management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
<ul style="list-style-type: none"> - Excess nutrient output can increase dissolved nutrient concentrations, leading to eutrophication and fisheries declines (-) - Excess nutrient output can lead to build up of particulate organic matter on the sea/ lake bed, affecting benthic diversity and productivity and fisheries that depend on these resources (-) - Particulate matter coming from fish cages can smother seagrasses and corals, affecting fisheries that depend on them (-) - Dissolved nutrients increasing primary productivity could have a positive effect on wild fish biomass (+) 	<ul style="list-style-type: none"> - Improve feed conversion factor - Promote research for improvement of feed quality (e.g. use feed ingredients with high digestibility) - Undertake carrying capacity estimations so that the environment can assimilate the nutrients released - Encourage environmental impact assessment and monitoring systems and integrated environmental assessments at the watershed scale, if appropriate - Improve site selection identification and suitability, avoiding sensitive habitats - Improve research and monitoring of waste management - Improve nutrient re-utilization by wider implementation of integrated aquaculture

Interactions and impacts resulting from release of diseases and parasites

Both cultured and wild fish are susceptible to the same pathogens and the same parasites in the aquatic environment, but it is likely that intensive aquaculture conditions increase their prevalence within the farm. Therefore, the risk of transmission of pathogens and parasites between wild and cultured fish is possibly increased as water moves freely between farm enclosures and the open environment, or when farmed fish escape and intermingle with wild fish. Aquaculture has been blamed for transmitting parasites and endangering wild fisheries. Costello (2009) presents evidence that salmon farms are the most significant source of sea lice on juvenile wild salmonids in Europe and North America. Krkošek *et al.* (2007) describe the impact of sealice infestation on pink salmon (*Oncorhynchus gorbuscha*) in Pacific Canada, sealice apparently causing significant declines in the wild populations of the species, although the latter impact has been challenged, since wild populations have recently had major increases. The decimation of the oyster industry (both fisheries and aquaculture) in Europe was due to disease apparently resulting from the transboundary movement of seed from places where the disease was present, to new culture areas.⁴ The pilchards imported for feed to Australian tuna farms

⁴ See: www.fao.org/fishery/culturedspecies/Ostrea_edulis/en

TABLE 8**Issues related to transfer of parasites and diseases between cultured and wild fish and management solutions within EAA**

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
<ul style="list-style-type: none"> - Transfer of pathogens from farmed to wild fish (-) - Transfer of pathogens from wild fish to farmed fish (-) 	<ul style="list-style-type: none"> - Follow national regulations and international guidelines for the introduction and movement of live non-native species/strains to the wild and for culture* or as feed for aquaculture - Follow national and international norms and regulations for the management of aquatic animal health (e.g. OIE, 2011) - Implement biosecurity frameworks including adequate control of seed quality and transport pathways (disease) and quarantine for non-native seed, rapid and safe harvest of diseased fish, adequate collection and elimination of dead fish outside the waterbody - Prevent escapes* - Improve husbandry and keep farmed densities low enough to avoid stress - Conduct monitoring and surveillance of diseases in wild fish surrounding farm sites

* As in Table 6.

are believed to have caused the massive viral epidemics starting in 1995 that killed a large proportion of the wild adult pilchard population in South Australian waters (Thorpe *et al.*, 1997).

Despite the above examples, much more is known regarding disease interactions among the host, the pathogen and the environment of cultured fish than for wild fish populations, because cultured fish are more easily observed. Also, once wild fish are infected by aquaculture farms or by other vectors, because of their low density, the disease is usually become less prevalence unless fish form large schools around cages. Clearly, scientific information on disease interchange between wild and farmed fish is still scarce and the evidence of impacts is variable (McVicar *et al.* 2006).

The issues related to transfer of parasites and diseases and possible management solutions within an EAA are given in Table 8.

Interactions and impacts resulting from release of drugs and chemicals

Like any land-based form of raising livestock where large numbers of animals are placed in a very limited space, aquaculture can provide various diseases and parasites with the ideal conditions to spread. Antibiotics and other chemicals can be administered to fish through medicated feed or through external treatments.

Antibiotics can be ingested by wild fish directly when they eat medicated feed that falls through the cages. These fish, in turn, may be caught and eaten by people, who thereby ingest limited amounts of antibiotic (Cabello 2006). This is undesirable, when one considers the development of bacterial resistance in

people. The general perception is that residues of these medications, however administered, will be taken up by the benthic infauna and epifauna to their detriment, and will bioconcentrate up the food chain, reducing the resistance to disease of demersal and pelagic fish and thus affecting fisheries. However, there is almost no direct evidence of such effects. Although there are relevant reviews of chemical use in aquaculture, including products not related to disease treatment containing elements such as copper and zinc, the potential impacts of these on fisheries and ecosystems need to be studied in more depth (Burrige *et al.* 2010).

Management solutions within EAA are similar to those indicated in Table 8. The responsible use of veterinary medicines and other chemicals in aquaculture must be included as relevant measures.

Income and increased livelihood opportunities

In general, the major contributions of aquaculture towards the improvement of human well-being are found in the wider economy and the sector as a whole. Here, job creation and investment opportunities not only involve fish farming, but also those activities that are involved in servicing fish farming (e.g. supply and servicing of the main equipment, production and cleaning of nets and rafts, veterinary services, feed production), processing, marketing, sales and transport. Small-scale fishermen, struggling with making fishing a viable livelihood, now often want to become fish farmers, as they find new opportunities in this sector. Also, aquaculture production and processing offers many livelihood opportunities to women, who often come from coastal fishing communities. This has been the case with salmon farming in southern Chile, with shrimp farming in countries such as Brazil and Nicaragua (Wurmann, 2011), and with catfish culture in Viet Nam (De Silva and Phuong, 2011; Davy *et al.*, 2012). In many countries there is constant movement between fishing and aquaculture; for example in Scotland, a significant proportion of fishermen would be willing to be fish farmers, and vice versa.⁵

Fisheries and aquaculture provide direct and indirect livelihood support to millions of people. In 2008, out of an estimated 44.9 million people who were directly engaged full time or part time in capture fisheries or aquaculture, an estimated 10.7 million were involved in aquaculture, or about one-quarter (24 percent) of the total number of workers, the largest proportion (more than 90 percent) being in Asia (FAO, 2011). However, progress towards carrying out socio-economic evaluations of the effect of the aquaculture industry on local communities and its interaction with employment in coastal fisheries and other local opportunities has been slow. Relatively little is known about fishermen's behaviour, preferences and strategies when confronted with an expanding aquaculture industry, taking into account the availability of other employment

⁵ AQCESS (www.abdn.ac.uk/aqcess).

opportunities. The consequences of changing coastal fishery patterns and management regimes on aquaculture opportunities, given other employment opportunities or drift to unemployment should be assessed to evaluate prospects for expansion of either of these industries.

There are some examples of aquaculture reducing the fishing stress on depleted populations by providing alternative income and opportunities to fishermen. For example, the culture of groupers is increasingly satisfying market demand and so is reducing fishing pressure on wild grouper stocks and the consequent reduction of use of destructive fishing methods. Aquaculture's facilitation of fragile habitat preservation (e.g. coral reefs) could also ensure longer-term fishery of this and other species associated with the reefs (De Silva and Phillips, 2007).

As an indirect effect of increased production and income, the growth of aquaculture has enhanced the strengthening of many fisheries institutions worldwide. Such is the case of Brazil, where the growing opportunities of the sector have contributed to the reorganization of the fisheries and aquaculture institution through the creation of the Fisheries and Aquaculture Ministry. This has also occurred in Chile and in Viet Nam (World Bank, 2005), where the rapid development of aquaculture has resulted in the strengthening of government fisheries and aquaculture institutions.

Aquaculture and fisheries interactions through markets and postharvest processes

The volume of world aquaculture production is currently becoming closer to the volume of world fisheries production for human consumption (FAO, 2011). Aquaculture production will continue to expand and have dramatic impacts on markets for wild fisheries. For example, prices paid to wild salmon fishermen and processors in the United States of America fell dramatically as world farmed salmon production expanded during the 1990s, causing significant economic difficulties for Alaskan salmon fishermen, processors and fishing communities (Knapp, Roheim and Anderson, 2007). United States shrimp fishermen have experienced similar effects of competition from farmed shrimp. Aquaculture development has been partly stimulated by overfishing of wild stocks, which has resulted in the inability of the capture fisheries sector to meet the growing demand for wholesome seafood products. Salmon farming emerged in the 1980s as wild stocks of coho and chinook salmon in North America dwindled and Atlantic salmon stocks were threatened in both America and Europe due to overfishing and loss of habitat. Growth in catfish and tilapia aquaculture has satisfied market demand in the whitefish markets, as harvests of the wild product have decreased considerably. Falling supplies of wild ground fish have also stimulated commercial production of farm-raised cod in Norway. In each of these cases, the aquaculture sector has emerged to increase fish supplies and try to meet the market demand.

Nearly 65 percent of shrimp consumed is produced by aquaculture, a result of continuing consumption linked to increasing incomes. On the other hand, aquaculture has been successful in bringing affordable fish (and protein) to consumers. It has also expanded availability of product to consumers, both in terms of geographic coverage and by prolonging (even abolishing) seasonality, and therefore, it has encouraged fish market development.

Aquaculture has also helped the fishery sector develop much more sophisticated distribution and logistics networks. For example, farmed salmon has greatly expanded and created new market opportunities for wild salmon. Farmed salmon has benefited consumers by lowering prices, expanding supply, developing new products and improving the quality of both farmed and wild salmon (Knapp, 2007).

Markets for aquaculture species and for wild fisheries products are considered “markets for seafood” (including freshwater species). However, for some species there is differentiation between the farmed and wild product, as in salmon and in some cases, for seabream and seabass, appealing to different customers and achieving different market price. Some consumers perceive wild fish as superior to farmed fish and are willing to pay a higher “premium” price for wild fish (e.g. the higher price of wild-caught as compared to farmed seabass in the Mediterranean markets). This is also true in many Asian countries; when wild-caught counterparts are preferred, most market prices for the former are about 20–30 percent higher than that of the cultured commodities (Knapp pers. obs). In some cases, such preference works against aquaculture market prices and final benefits for the producers. However, most consumers worldwide, care more for price, and therefore larger aquaculture outputs of a species that has a wild counterpart will lower the price of both types of fish. This could be also the case if there is a larger output of wild fish of similar quality. In general, the degree of market interaction between fisheries and aquaculture depends on the total output (fisheries plus aquaculture) and the market’s ability to distinguish between the two origins. The latter is influenced by the industry’s ability to highlight those differences in their marketing strategies.

The positive and negative issues related to markets and possible management solutions addressing the negative impacts within an EAA are given in Table 9.

Issues related to governance and ability to achieve

For most issues dealing with aquaculture inputs, resource use and outputs, there are key common governance root-problems/governance issues. The most common issues include the existence of non-related policies for fisheries and aquaculture, lack of integrated planning, of communication, of understanding of the interactions, of adequate research, of training and insufficient consideration of the different nested geographical scales (Figure 6). In general, there is a lack of an ecosystem approach to fish production in general.

TABLE 9
Issues related to conflicts and synergies between aquaculture and fisheries in the market and management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for the negative effects
<ul style="list-style-type: none"> - Aquaculture can supply a homogeneous product of similar size, quality and consistency throughout the year compared to fisheries (- for fisheries) - Aquaculture has been forced to understand and respond to the needs of consumers and customers with the development of a range of product forms, quality standards, packaging, and timing and volume of fish deliveries, long-term contracts, supply guarantees, payment terms, etc. This has facilitated the way towards better postharvest standards for fisheries (+ for fisheries and for the consumer) - Aquaculture has often lowered fish prices through increased and continuous supply, market access and market competition (-for fisheries) - Aquaculture production is changing consumer behaviour, resulting in the development of new markets and increased fish consumption (+ for fisheries) 	<ul style="list-style-type: none"> - Improve fishing techniques and processing of fishery products - Find alternative fishing resources - Move from fisheries to aquaculture - Develop intersectoral marketing strategies with strong focus on quality of products - Differentiate aquaculture and fisheries pricing structures - Focus fisheries more on marketing, segmentation and more forward integration into the value-chain - Develop policies that would provide incentive to value and not just to volume - Involve the fishermen more in management

Other external factors affecting ability to achieve (such as climate change) can exacerbate some negative interactions. For example, increased temperatures can enhance aquaculture-induced eutrophication processes, with negative impacts on fisheries (Table 7). Also, climate change can affect fishmeal fisheries and reduce availability of related ingredients for aquaculture feeds, although a positive downside to this is that aquaculture can be forced to reduce its dependency on these fisheries (De Silva, 2012).

Prioritization of issues: assessing the risks

As seen in the previous section, aquaculture-fisheries interactions and issues differ among countries and regions. For example, in some places escapees are seen as threats to fisheries, while in others, aquaculture-based stocking of waterbodies is seen as a solution for food security, and perhaps risks are underestimated.

In following the steps recommended in Figure 2, after the scoping and issue identification (done for a particular location, waterbody, country, etc.), it is necessary to focus on those issues and threats that could become major obstacles to achieve the high-level policy goals and management objectives for the fish production sector (fisheries and aquaculture).

The outcomes from this activity should be a decision for each of the identified issues as to whether or not there should be direct intervention, and if so, how soon and resources required (FAO, 2010b, FAO EAF toolbox)⁶. Most robust

⁶ www.fao.org/fishery/eaf-net/topic/166272/en

prioritization processes are based on risk assessment⁷ using formal risk assessment methods (Arthur *et al.*, 2009). In some instances, it is possible to address prioritization of issues through participatory stakeholder analysis in the form of simple risk ranking with minimal levels of data and high stakeholder involvement. Within the context of the present analysis, we are dealing with a hazard generated by an organism (e.g. escaped fish), a physical condition (e.g. release of antibiotics or other chemicals), an action (e.g. the clearing of a mangrove area to build aquaculture ponds), etc. that may cause harm and therefore potentially create a risk for fisheries. Furthermore, risk assessment should be done for all the environmental, social and governance issues in order to identify those that require direct intervention and the level of urgency.

Developing the management system to minimize aquaculture's negative effects on fisheries

In the previous section, we have identified the main issues and provided a summary of potential management measures. In this section, we summarize the next steps using some elements of the tool box template developed for the ecosystem approach to fisheries (FAO EAF Toolbox) and the EAA guidelines (FAO 2010b).

Setting operational objectives

After identifying the issues (ecological, social, economic or institutional) that require direct intervention, the next step is to develop a management system that will deliver successful outcomes. This requires clearly specifying what we want to achieve and what level of better outcome we are aiming at with the proposed management measures. These are known as operational objectives, and they need to be clear, measurable, time bound and directly linked to one or more of the high-level objectives and policies (Figure 2). For example, to address issues identified in Table 7, an operational objective could be to reduce farm nutrient outputs that induce eutrophication and fishery losses in a lake (fish kills by oxygen depletion) by 30 percent annually. As another example, an operational objective to deal with issues in Table 6 could be to reduce fish escapes from farms by 50 percent in the next two years and by 80 percent in the next four years.

Operational objectives should be developed in consultation with stakeholders because they define precisely what the management plan is designed to achieve and therefore what changes and improvements are required in aquaculture systems and their management, in the related fisheries and any other arrangements that may need to change.

To assess effectiveness of the measures in achieving operational objectives, there needs to be a way of evaluating the success of the management system. This requires indicators to measure performance and also targets (limit value,

⁷ Risk assessment is the process of assessing the likelihood and consequences of an event.

threshold, etc.). For example, for the first case above, we could use the feed conversion ratio (FCR) and aquaculture biomass per area as indicators. Indicators and targets would have to be agreed upon by the relevant stakeholders based on the best available information.

The monitoring of indicators, survey type and frequency should be proportional to both the predicted and actual impacts. Monitoring programmes and the use of indicators can be conducted at different levels. Farmers and/or authorities can perform simple and inexpensive surveys when impacts are expected to be minor. The outputs of the surveys should be an impact mitigation plan to take corrective actions over the management measures. It could also involve a review of the targets to make them more realistic.

Management measures/options

A critical step of the management system is to determine which management measure or combination of measures will most likely achieve each of the operational objectives given the available resources and any other constraints. This involves assessing which of the current formal or informal arrangements have deficiencies or inefficiencies and identifying potentially better alternatives. Each option should be evaluated based on its cost effectiveness, impact on risks and operational objectives, likelihood of adoption, etc. to determine which is the most appropriate. Many of the management measures must involve not only EAA but also EAF, especially when dealing with issues such as fisheries for wild seed or the management of fisheries to produce fishmeal or fish oil for pelleted feeds or for direct feeding with wet fish.

Tables 2 to 9 above identified the main issues and proposed management measures, some of which are expanded upon in the sections below.

Risk analysis and environmental impact assessment

A number of frameworks have been developed to minimize aquaculture's environmental and social risks, including the *Code of Conduct for Responsible Fisheries* (FAO 1995) and various guidelines for aquaculture development in support of the code (e.g. FAO 1996, 1997, 2010b).

Management measures should include some form of environmental impact assessment (EIA) and/or risk analysis (see Arthur *et al.*, 2009; FAO, 2009) prior to embarking on aquaculture activities that may impact aquatic environments and fisheries, including as well the monitoring of ecosystem and fishery changes; for example, this should always be done when using alien species or strains.

In the case of alien species, the solution is not to ban these – or to abandon regulation of their movement – but rather to assess associated risks and benefits to local fisheries, and then, if appropriate, develop and implement a plan for their responsible use. Relevant measures and recommendations for the

use and movement of alien species and strains for aquaculture and CBF can be found in several institutional frameworks and documents. Good examples are the advice produced by the European Inland Fishery Advisory Commission (EIFAC) (Turner, 1988), the *Code of Practice on the Introductions and Transfers of Marine Organisms* produced by the International Council for the Exploration of the Sea (ICES, 1995), the FAO guidelines on *Health Management for Responsible Movement of Live Aquatic Animals* (FAO, 2007), and the guidelines on genetic resource management (FAO, 2008), among others.

Proper siting and consideration of carrying capacity

Aquaculture production facilities should adjust their production to the carrying capacity of the relevant waterbody and socio-economic system; this including fisheries. Each ecosystem has a different capacity to absorb and assimilate excess loading of organic compounds and nutrients from a farm or capacity to absorb social changes, habitat modifications, etc. that come with the farm. There is a need to examine carefully the desirability of different nutrient levels in different parts of an aqua-fish-ecosystem from the perspectives of the various users, and in terms of the stability of the system as a whole.

Many of the space and habitat-related impacts of aquaculture development on traditional fisheries can be reduced or eliminated through adequate siting and zoning of aquaculture areas. Zoning or allocation of space is a mechanism for more integrated planning of aquaculture development to avoid conflicts with fisheries (e.g. sensitive wild fisheries, spawning and nursery areas), as well as its better regulation. There is much literature and guidance relating to integrated natural resource management such as integrated coastal zone management (ICZM) and integrated watershed management (IWSM).

There are geographic information system (GIS) tools that can assist decision-making for site selection and modelling within and among all boundaries associated with aquaculture development and management, including the spatial requirements and boundaries for relevant fisheries. Modeling the nutrient budgets for individual farms could help find the optimal balance of nutrient release to minimize impacts on fisheries or even to enhance primary productivity in support of wild fisheries. There are many immediately available decision-making tools that could be used and many aquaculture models (e.g. carrying capacity) can be run inside GIS, or be spatially related to optimize aquaculture-fisheries interactions by GIS (Aguilar-Manjarrez, Kapetsky and Soto, 2010)⁸.

Better management practices (BMPs) and codes of practice (COPs)

BMPs are a practical and economically feasible way to reduce adverse environmental impacts of aquaculture at the farm level and also at larger

⁸ Also see GISFISH (www.fao.org/fishery/gisfish/index.jsp).

scale, and so reduce conflicts with fisheries (Mohan and De Silva, 2010). Implementing BMPs requires action from both government (in the form of better policy, regulation, enforcement and planning and management procedures) and industry (through BMPs). However, BMPs must consider the monitoring and adaptive management of the added impacts of many farms, and therefore the need to consider the aquaculture zone and/or watershed scale. BMPs and COPs can involve, for example, more efficient ways to reduce feed losses and to improve FCRs, therefore reducing the nutrient release to waterbodies. They can also involve practices that minimize the risks of escapees from farms, the spread of diseases, etc.

Discouraging unsustainable use of wild seed and juveniles

All forms of CBA need to be evaluated in light of their social and economic viability, the wise use of fishery resources and their environmental impact as a whole. Greater efforts must be made to produce seed in hatcheries and make them available, especially to small-scale farmers. More efforts are needed in terms of research, investment and capacity building, and to ensure that continuing seed and broodstock fisheries are managed sustainably and through implementation of EAF.

Discouraging unsustainable use of fish for aquaculture feeds

National and local institutions and the aquaculture industry as a whole must consider the broader scale impacts of aquaculture on fisheries through the collection of fish for direct feed to aquaculture and the use of fishmeal and fish oil in feeds (Tacon *et al.*, 2012; FAO, 2011). Efforts must be made to ensure that the fisheries that provide these inputs are managed according to EAF and that the aquaculture industry is moving towards the use of less fishery-dependent feeds, especially where fish can be used for direct human consumption.

Encouraging sustainable culture-based fisheries (CBF)

There is potential for improvement of impoverished fisheries species close to extinction and poverty alleviation through cooperative organization to enhance production from a common resource with few inputs: lakes and reservoirs, and seasonally flooded floodplains. Stocking of fish in areas amenable to fencing, especially those already partially enclosed by embankments or dykes, may result in yields significantly greater than those from wild fisheries. There appears to be great potential for developing these systems across large areas in both Asia and Africa, as there are many suitable sites; and entry costs for these systems may be low. Nevertheless as mentioned earlier, all forms of CBF must include some kind of risk assessment before taking place.

It is important to move beyond the focus on the fisheries objective and include the other ecological and social functions of the watershed or waterbody in the decision-making process of the stock enhancement programme. Although knowledge about specific ecosystems (of which fish stocks to be enhanced are

a component) is less than perfect, precautionary approaches based on the best information about specific watershed/coastal zone and ecosystem processes should be considered and applied (Molony *et al.*, 2003).

Measures to improve governance

Government institutions must pay closer attention to fisheries issues in any aquaculture activity (Figure 6), since, in general, the interdependency and interaction due to the use of common resources can be much stronger than with other sectors. Often there is a need for new institutional arrangements to manage common-pool aquatic resources and sustain investment in them, and this requires a review of the fisheries sector policy, considering both fishery and aquaculture. There should be a strong element of co-management where user organizations play an important role, frequently facilitated by various interest groups. In this regard, better and more effective communication systems and approaches are needed so that the aquafarmers can understand the fisheries issues and vice versa.

Government organizations have an important role to play in synergistic initiatives through creation of supportive institutional arrangements for research, extension and capacity building. Government institutions must also play their role in developing proper regulation and enforcement systems.

Establishing water basin/waterbody authorities to deal in a coordinated manner with both fisheries and aquaculture (as well as other users) can be very useful to resolve conflicts and to assess, monitor and take action on the added effect of many aquaculture farms and their interaction with fisheries.

Although catching and farming fish produce a similar end product, the process and activities reaching that end are different. Women and children have important roles to play as harvesters, processors and distributors of fish. As many areas promote aquaculture as an alternative to fishing, the roles of all stakeholders need to be considered to avoid displacing certain members of society and to ensure that new opportunities can be realized. A water basin authority can facilitate the interaction of stakeholders and a more participatory decision-making process with a more equitable distribution of resources.

Clearly, there is a need for monitoring and management on a system-wide basis to maintain the health of aquatic ecosystems and to implement corrective measures when needed. Monitoring and enforcement of rules is a key element of any active management system for common-pool resources. This is also relevant when self-governance arrangements exist, since rule monitors (enforcers) must be accountable to the self-governing institutions. This is relatively easy to achieve in clearly bounded systems under the control of a single body, such as for small waterbodies (Garaway, Lorenzen and Chamsingh, 2001). Where this is not the case, however, governments have to play a greater role in monitoring

and enforcement. This may lead to problems, unless government enforcers are also accountable to the self-governing institutions. Difficulties in enforcing rules are the most important cause for changes in community rules (Barbosa and Hartmann 1998). Monitoring and enforcement has to look carefully into the delicate and often complex aquaculture-fisheries interactions, and this requires aquaculture and fisheries authorities to work together, even though in many countries the two sectors are taking separate routes after aquaculture's fast growth.

The establishment of national programmes and international cooperation for research activities dealing with the interaction between aquaculture and capture fisheries (including the social aspects) would be useful in both marine and freshwater environments. The possibility of developing pilot projects at the waterbody scale based on the improvement of positive interactions between aquaculture and capture fisheries should be considered.

Making the management system operational

Implementing a management system to deal with aquaculture-fisheries interactions in a specific location/geographic area needs an operational plan that outlines, in detail, what would need to be done by whom, by when, and where. This includes identifying new activities and actions that need to be implemented and those existing activities and actions that need to be changed, as well as other activities that may need little or no change. The operational plan must include the timing, the resources (human and monetary), the institutions and stakeholders that need to work together, and must consider the practicality or feasibility of the proposed management arrangements.

When the feasibility is confirmed, all proposed management actions and arrangements need to be incorporated into a formal fishery and aquaculture resources management plan which has an appropriate legal basis. This can require drafting legislation or regulations, but for local small-scale aquaculture and fishery activities, other less formal documentation may be applicable.

Monitoring, evaluation and review of performance is the “final” step in the adaptive management planning process. It is essential to ensure that adequate performance is being generated against current objectives but also that the fish production from aquaculture and fisheries is as expected by local communities and other stakeholders.

As explained above, planning the implementation of management measures/actions can take place at a waterbody scale, for example, planning a new cage aquaculture development in a lake or coastal ecosystem. However, planning at the country level may also be needed; for example, in a country producing fishmeal for export and also for local aquaculture (e.g. Chile), the planning for better integration of fisheries and aquaculture may need to consider nutrient

fluxes (in the fish feeds), and costs and benefits of exporting fishmeal versus using this for local aquaculture. It is possible that fishmeal produced and used by aquaculture in the country contributes to more livelihoods in terms of jobs and income (added value) than fishmeal that is merely exported. Planning of an increased fish output by means of CBF and stock enhancement also may require whole-country planning, or even broader regional planning, if international watersheds are involved.

Using the ecosystem approach to facilitate implementation of the Bangkok Declaration

The issues identified in this review are especially relevant in the achievement of two objectives of aquaculture development as stated in the Bangkok Declaration (NACA/FAO, 2001):

- achieving its full potential as a food-producing activity that makes a net contribution to global food availability, household food security, economic growth, trade and improved standards of living; and
- as an integral component of the development, aquaculture shall contribute towards the sustainable livelihood of the poorer sectors of community, the promotion of human development and the enhancement of social wellbeing.

Additionally, the Bangkok Declaration stated that no activity should jeopardize the others, and that the use of technology and observation of the *FAO Code of Conduct for Responsible Fisheries* (FAO, 1995) were meant for the harmonious coexistence that underlies the principles of sustainable development.

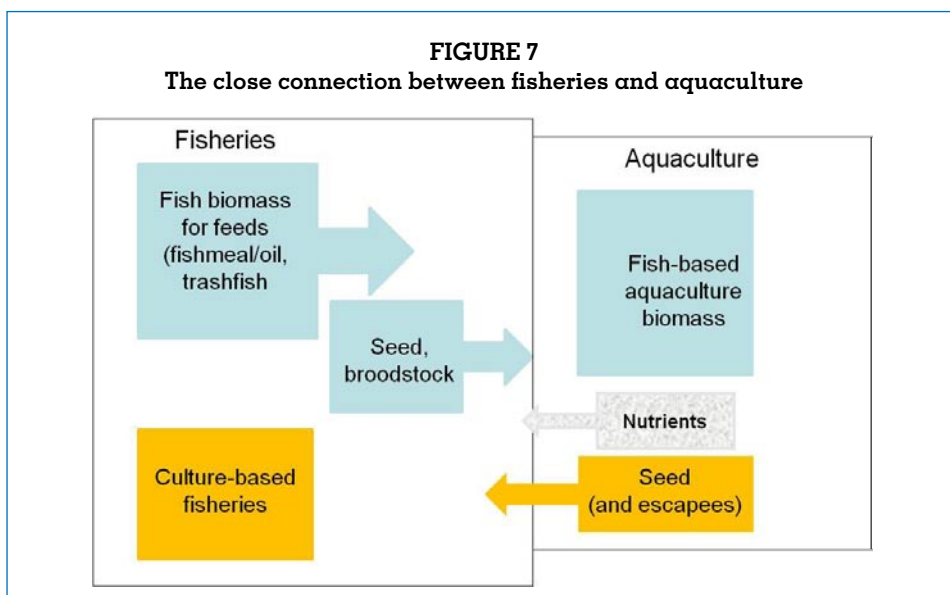
The ecosystem approach to aquaculture (EAA) can contribute to the achievement of the Bangkok Declaration commitments and to the *FAO Code of Conduct for Responsible Fisheries* through improvement of environmental and social sustainability by efficient use of resources, efficient production methodology, minimizing of unwanted outputs, improved income and equitable sharing of benefits. The EAA also facilitates integrated coastal zone development, while reducing conflicts with other sectors and coastal communities. In the present case, aquaculture development should minimize negative impacts on fisheries while enhancing potential contributions to this subsector and better integration of fish production.

In the long run, all significant commercial seafood supplies and non-food fish will come from one of three sources: i) fish farms/aquaculture; ii) aquaculture-enhanced fisheries or iii) fisheries that adopt efficient management systems. The first two pose challenges to aquaculture and require emphasizing the synergies and complementarities between fisheries and aquaculture, including institutional, social, economic, environmental and biotechnological aspects. Acknowledgement of these interactions offers opportunities for sectoral

development, for increasing food security, reducing poverty and improving rural livelihoods. The two subsectors need to form partnerships, as both are strongly linked (Figure 7), both depend on healthy aquatic environments and both are impacted by other development activities. For example, as mentioned above, in the next decades, CBF will likely play a much greater role in sustaining and increasing capture fisheries yield for ultimate public good, including achieving conservation objectives. Therefore, it is important to analyze the present status of CBF and stock enhancement, comprehensively assess the impacts of the activities, and identify constraints and ways to improve their ecological, economic and socio-economic benefits by implementing an ecosystem approach to the overall fish production. It is also necessary to improve our understanding on the potential and actual environmental impacts of stocking and escapees worldwide beyond salmon!

Environmental degradation, climate change and overfishing will continue to impact the wild fisheries resource in the coming years, although efforts can be made to mitigate the impacts. Aquaculture’s reliance on fisheries for feeds will become increasingly challenging and less sustainable (Tacon *et al.*, 2012).

Joint use of the environment and sustainable sharing of resources to the ultimate benefit of communities require that individual action not be treated in isolation, but as part of a much larger entire waterbody/hydrological system. This approach necessitates an understanding and awareness of the intricate interactions that make it sustainable. The strategy must unambiguously identify the roles of all stakeholders, assigning responsibilities and benefits, and in most cases revolve around the watershed, waterbody or relevant coastal zone as the geographic area of delimitation of actions and management.



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Improving biosecurity: a necessity for aquaculture sustainability

Expert Panel Review 3.3

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Abstract

The implementation of biosecurity measures is vital to the future development of aquaculture, if the culture of aquatic species is to make it possible to feed the global human population by 2030. Biosecurity includes control of the spread of aquatic plant and animal diseases and invasive pests, and the production of products that are safe to eat. For controls on diseases and invasive pests, it is necessary to implement programmes that involve all regional countries. Lessons from measures implemented in Asia need to be expanded/upscaled in Latin America, Africa and other emerging aquaculture regions. Such development will make countries more self sufficient and will feed local populations.

Globally, there is good evidence that aquatic animal diseases and invasive animal and plant pests are being spread by hull fouling and ballast water in shipping, and serious aquatic animal diseases by the international trade in ornamental fish. While there has been a growing awareness of the danger of ballast water transfer, hull fouling remains a serious problem. It is widely recognized that ornamental fish present a disease risk, but individual countries have tried to address this alone, and there has not been an international effort to control the trade.

Developments in genetics and molecular biology hold great potential for disease control, either by breeding for disease resistance, or by the use of rapid, specific, culture site testing. Currently, there is no evidence that the use of antibiotics in aquaculture poses a threat to human health or that antibiotic-resistant strains have developed; however, the future use of genetically modified aquatic organisms (GMOs) may negate the need for chemotherapy. Cultured aquatic organisms, selected for disease resistance or rapid growth, are likely to become more acceptable, and probably necessary, to feed the rapidly growing global population.

Most global aquaculture occurs in developing Asian countries, in which aquaculture products can harbor zoonotic parasites, and there is a need to treat such products to negate the threat of parasitic zoonoses and permit international export. Climate change is likely to be a major influence on aquaculture in the future, with impacts on coastal aquaculture through increased sea levels affecting coastlines, and acidification. To feed the growing global population, it will be necessary to culture new species, for which research on diseases and invasiveness will be necessary to acquire the information necessary to implement biosecurity measures.

KEY WORDS: *Aquaculture, Biological invasions, Biosecurity, Genetically modified organisms, Transboundary aquatic animal diseases.*

Introduction

More than 200 species are produced in aquaculture worldwide; some 25 of these are of high value and traded globally. A successful harvest can be very profitable, and this has spurred the expansion of aquaculture production in both area and geographical range. As aquaculture becomes more intensive, new diseases and other problems are likely to emerge, and old diseases will appear in new locations.

Subasinghe, Bondad-Reantaso and McGladdery (2001) in a review paper entitled “Aquaculture development, health and wealth” as part of the *Technical Proceedings of the Conference on Aquaculture in the Third Millennium* (FAO/NACA, 2001), described how disease has become a primary constraint to sustainable aquaculture production and product trade, provided some examples of the socio-economic impacts of transboundary aquatic animal diseases (TAADs) as well as measures to deal with aquatic diseases, and evaluated the effectiveness of health management programmes and what can be done to improve health management and reduce disease risks. The current review takes a broad approach to as many aspects and issues of biosecurity as possible and the role of effective biosecurity in the sustainable increase in aquaculture production.

The Food and Agriculture Organization of the United Nations (FAO) defines biosecurity as a strategic and integrated approach that encompasses both policy and regulatory frameworks aimed at analyzing and managing risks relevant to human, animal and plant life and health, including associated environmental risks (FAO, 2007a). It covers food safety, zoonoses, introduction of animal and plant diseases and pests, introduction and release of living modified organisms (LMOs) and their products (e.g. genetically modified organisms or GMOs), and the introduction of invasive alien species. It is a holistic concept of direct relevance to the sustainability of agriculture, public health and protection of the environment, including biological diversity. An essential element of sustainable agricultural development and food production, the overarching goal of biosecurity is to prevent, control and/or manage risks to life and health appropriate to the particular biosecurity sector.

Many factors are driving the current interest in biosecurity. Globalization (increase in volume and diversity) of trade in food, plant and animal products; changing food production practices and climate with new technologies; heightened awareness of biological diversity; greater demand for public health and environmental protection and other emerging issues such as rising food prices, climate change and animal welfare, are some of these. The benefits of improving biosecurity through safeguarding plant and animal life and health, enhancing food safety, promoting environmental sustainability, protecting biodiversity and a long-term strategic response to rising food prices are also recognized (Bondad-Reantaso, Lem and Subasinghe, 2009).

In aquaculture, biosecurity refers to the application of appropriate measures (e.g. proactive risk analysis) to reduce the probability of an organism spreading to individuals, populations or ecosystems, and to mitigate the adverse impacts that may result from such (Subasinghe and Bondad-Reantaso, 2006). It is concerned with management of aquatic animal health, conserving aquatic biodiversity and reducing public health risks associated with production and consumption of aquaculture products. This analysis incorporates the best information available on aspects of husbandry, epidemiology and good science.

Sections 3.11 (managing aquatic animal health), 3.13 (applying genetics to aquaculture), 3.14 (applying biotechnology) and 3.15 (improving food quality and safety) of the *Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (Subasinghe et al., 2001) are all relevant to biosecurity. Traditionally, such concerns have been addressed using the sectoral approach to biosecurity, and what is lacking is a holistic systems approach to aquatic animal health management and biosecurity. Since the 2000 Aquaculture Millennium Conference, introduction of TAADs through global trading, and food safety and public health issues continue to challenge the aquaculture sector, and new issues have emerged. These include TAADs associated with the global trade in ornamental aquatic animals; a spread of invasive animals and plants, viruses, microbes and toxic algae by vectors; and climate change scenarios affecting biosecurity.

Implementing effective biosecurity is vital to the future development of aquaculture, if the culture of aquatic species is to make it possible to feed the global human population by 2030. Biosecurity concerns including food safety, public health risks on the use of veterinary medicines, bioinvasions and the use of aquatic GMOs are discussed in this review. Major issues and trends during the last decade are presented, followed by an elaboration of what has been achieved by different stakeholders. The outcomes of the expert panel presentation during the Global Conference on Aquaculture 2010, held in Phuket, Thailand in October 2010 are also presented. The paper concludes with a number of recommendations and the way forward.

Major biosecurity issues and trends during the last decade

Transboundary aquatic animal diseases

The health of aquatic animals is not always readily visible, as feed consumption and mortalities are hidden under water. Thus, attention is required to monitor their health. Because of the great diversity of the aquaculture sector in terms of species cultured, the range of culture environments, the nature of containment, the intensity of farming practices and the variety of culture and management systems, the task of managing aquatic animal health and biosecurity governance is particularly challenging. Once a pathogen has been introduced and becomes established in the natural aquatic environment, there is very little or no possibility for either treatment or eradication; therefore, prevention is the best strategy.

Transboundary aquatic animal diseases (TAADs) are aquatic animal diseases that are highly infectious, have the potential for very rapid spread irrespective of national borders and can cause serious socio-economic consequences. Domestic and international trade are important pathways for the introduction of TAADs. Increase in trade will also increase the risk of new mechanisms by which pathogens may be introduced and spread to new areas together with host movement. In aquaculture, many examples exist of TAADs that created serious negative impacts, including: direct production losses, direct and indirect impacts on income and livelihoods/employment, increased operating costs, restrictions on trade, impacts on biodiversity, loss of market share or investment, loss of consumer confidence, and in some cases, collapse of the sector (Subasinghe, Bondad-Reantaso and McGladdery, 2001; Bondad-Reantaso *et al.* (2005); Bondad-Reantaso, Sunarto and Subasinghe, 2007). Available estimates on losses due to TAADs, reviewed by Bondad-Reantaso *et al.* (2005), range from as low as USD17.5 million (white spot disease (WSD) of shrimp in India in 1994) to as high as USD650 million (for yellowhead virus and WSD in Thailand in 1994) to a global estimate of USD3.019 billion in losses due to shrimp diseases. In a review of disease issues in the shrimp aquaculture industry up to 2005 (Flegel *et al.*, 2008), it was estimated that production losses due to disease over the preceding 15 years amounted to approximately USD15 billion. According to a survey conducted by the Global Aquaculture Alliance, approximately 60 percent of disease losses in shrimp aquaculture could be attributed to viral diseases and approximately 20 percent to bacterial diseases (Flegel, 2006b), indicating that 80 percent of the disease losses were attributed to only two pathogen groups, with viruses having approximately four times more negative impact on production than bacteria. Movement of live aquatic animals has been recognized as a major pathway for the introduction and spread of major TAADs. Fish are the most globally traded commodity, with a world value of USD93 billion for 2007 (Bondad-Reantaso, Lem and Subasinghe, 2009).

The current period of rapid change in the international trading environment has changed the disease situation in aquaculture rapidly and in an unpredictable way. Factors contributing to the current disease situation in aquaculture include: increased globalization of trade and markets: intensification of fish-farming practices through the movement of broodstock, postlarvae, fry and fingerlings; introduction of new species for aquaculture development; expansion of the ornamental fish trade; enhancement of marine and coastal areas through the stocking of aquatic animals raised in hatcheries; the unanticipated interactions between cultured and wild populations of aquatic animals; poor or lack of effective biosecurity measures; slow detection of emerging diseases; the misunderstanding and misuse of specific pathogen free (SPF) stocks; climate change and human-mediated movements of aquaculture commodities. Indiscriminate and unregulated global movement of aquatic animals has extended the geographical range of important TAADs and has caused serious disease outbreaks (Bondad-Reantaso *et al.*, 2005).

TAADs include: (1) epizootic ulcerative syndrome (EUS), whose original distribution was in Asia and the United States of America, which has recently expanded its geographic range to Africa (in 2006 and is now present in at least four countries in the African region) affecting mainly wild and some cultured populations; (2) koi herpesvirus (KHV), which has spread infecting the important food fish the common carp (*Cyprinus carpio*), the high-value ornamental koi carp and wild carp populations; and (3) infectious salmon anemia (ISA) and sea lice that have cost the salmon-producing countries millions of dollars in losses annually. Major European oyster-producing countries have experienced severe mortality events, including losses caused by the protozoan parasite *Bonamia ostreae*, which was transported from North America, and oyster herpesvirus (OsHV-1), which has spread with culture of Pacific cupped oysters (*Crassostea gigas*). White spot disease (or white spot syndrome virus, WSSV), considered as the most serious global pathogen of cultivated shrimp, has spread to more than 20 shrimp-producing countries. Viral nervous necrosis (VNN) is an important disease of cultured and wild marine fish, affecting almost 30 species.

TAADs, risk analysis and the ornamental fish trade

The *Aquatic Animal Health Code and Manual of Diagnostic Tests for Aquatic Animals* (OIE, 2011a,b) of the World Organisation for Animal Health (OIE) both recognized the international spread of disease via trade in ornamental aquatic animals. Recent changes to the global aquatic animal disease situation, and the importance of pathogens that infect ornamental fish (primarily cyprinids) are increasingly reflected in the OIE list of diseases, which now includes KHV and EUS, as well as spring viraemia of carp (SVC) and bacterial kidney disease (BKD). The inclusion of KHV and EUS, allows competent authorities to require international health certificates indicating freedom from these diseases, thus avoiding the need for import risk analyses (IRAs).

It was generally assumed that the risk of disease introduction in importing countries by the ornamental fish trade was theoretical, and that the likelihood of negative impacts resulting from the trade was very low. This was due to an absence of hard evidence linking ornamentals to serious disease outbreaks in native populations, belief that escapes or releases of aquarium-held ornamentals into natural waters were rare, and when they did occur, the chances of ornamental fishes surviving in temperate aquatic systems was unlikely (Davenport, 2001). The pathogens of ornamental fish and invertebrates and their host specificities are very poorly known, making assessment of the risk of establishment in new aquatic environments and hosts, and their environmental impacts, difficult to assess. Governments have had difficulty in effectively regulating the highly complex ornamental trade, due to its huge volume (>1 billion ornamental fish moved annually), the large number of species involved (>4 000 freshwater and 1 400 marine species), and the large number of exporting and importing countries (>100) (Whittington and Chong, 2007). In addition, the high frequency of transshipment and relabeling obscures both the source (e.g. from wild-caught

or cultured stocks) and the country of origin (Davenport, 2001; Latiff, 2004; Arthur *et al.*, 2008). The world's largest producer, Malaysia, for example, with a 2007 production of ~558 million ornamental fish and plants, exports much of its production via Singapore (Ng, 2009). Further difficulties arise because the industry has been resistant to regulation and because many countries accept "health certificates" based on the absence of gross signs of disease, without knowledge of the health status of the production facility, the origin of stock, surveillance, or the fish being shipped having been screened for parasites and diseases.

The international trade in ornamental aquatic animals has been shown, both theoretically (through IRAs) and actually (Lumanlan *et al.*, 1992; Hedrick and McDowell, 1995; Sano *et al.*, 2004; Iida *et al.*, 2005; Sunarto and Cameron, 2005; Bondad-Reantaso *et al.*, 2005; Whittington and Chong, 2007) to pose serious risks of introducing TAADs to new areas through the movement and escape or release of infected animals. National governments, particularly of countries in semitropical and tropical latitudes, have become increasingly aware of the potential environmental and pathogen risks posed by the ornamental trade and the difficulties of accurately assessing and managing these risks. They will thus be increasingly inclined to adopt a more precautionary approach to the movements of ornamental species.

The European Union (EU) has introduced regulation of the ornamental fish trade, adopting a risk-based approach to disease control. Regulations introduced in 2008 and 2009 include conditions for marketing, certification requirements, possible vector species, a model health certificate, a list of permitted third countries, ornamental fish susceptible to listed diseases, and the suspension of imports from Malaysia of some ornamental cyprinid fishes.

Risk management for aquatic animal pathogens outside those in the OIE Code must be justified by IRA. During the past decade, several IRAs have been conducted for ornamental aquatic animals (Table 1). With the exception of the recent IRA for gourami iridovirus by Biosecurity Australia (2009), such IRAs have considered many hosts and pathogens, and have many weaknesses. Ornamental fish are a special case in live animal trade where the OIE guidelines for IRAs may need to be revised, or where countries such as Australia with very high appropriate level of protection will have to greatly reduce the number of species traded and the number of sources permitted for hazard identification and risk assessment (Whittington and Chong, 2007).

An example of a more "specific" IRA for ornamental aquatic animals is that for gourami iridovirus and related iridoviruses conducted by Biosecurity Australia (2009). The study concluded that gouramis, cichlids and poeciliids pose an unacceptably high level of risk and recommended that in addition to existing import conditions, fish in these families should either be batch tested post-

TABLE 1
Summary of risk analyses completed on ornamental aquatic animals

Risk Assessment	Commodity	Importing Country/ Exporting Country	No. Hosts Considered	No. Potential Hazards in Preliminary List	No. Hazards Fully Assessed	Hazard: Host Ratio	Hazards Fully Assessed as % of Preliminary Hazards
Khan <i>et al.</i> (1999)	Live ornamental finfish	Australia/ Global	605 genera	104	44	0.17:1	42.7%
Hine and Diggles (2005)	Ornamental fish & marine invertebrates	New Zealand/ Global	394 genera and species	>500	35	2.4:1	7.9%
Biosecurity NZ (2009) *			+158 genera	+42	+8		
			Total of approx. 1300 species	>542	43		
Biosecurity Australia (2009) **	Ornamental finfishes	Australia/ Global	All allowable taxa	29	29	–	100%

* This study was a supplement to the earlier IRA by Hine and Diggles (2005).

** IRA was restricted to consideration of gourami iridovirus and related viruses (total of 29 strains/isolates). The study considered all freshwater and marine ornamental fishes allowed for importation (currently some 284 listings; see www.environment.gov.au/biodiversity/trade-use/lists/import/pubs/live-import-list.pdf); as these include listings at the family, genus and species level, no exact number can be calculated; however, the number of potential species must be in the thousands.

arrival in Australia to show freedom from iridoviruses of quarantine concern or that importations should be approved only if they are from countries, zones or compartments known to be free of iridoviruses of quarantine concern (based on active surveillance).

TAADs in shrimp culture and other technological developments

Transboundary movements of viral pathogens is a particular problem in shrimp aquaculture. Crustaceans may carry low levels of one or more non-host specific viral pathogens, even lethal ones, as persistent infections for long periods without gross signs of disease. These active viruses can be transmitted to naïve shrimp or other crustaceans, causing lethal infections, and can also be transmitted from broodstock to apparently normal larvae and postlarvae, with subsequent disease in rearing ponds stocked with the infected postlarvae. These hidden viral infections pose a great risk when living crustaceans destined for aquaculture are moved transboundary outside their enzootic range (Flegel, 2006c). This has resulted in several major shrimp viral epizootics, most notably for *Penaeus stylirostris* densovirus (PstDNV) in *Litopenaeus stylirostris* and *L. vannamei* in the Americas (Lightner, 1996), WSSV in all cultivated shrimp in Asia and the Americas (Flegel, 2006b), Taura syndrome virus (TSV) in *L. vannamei* in Asia (Nielsen *et al.*, 2005) and more recently infectious myonecrosis virus (IMNV) in *L. vannamei* cultivated in Indonesia (Senapin *et al.*, 2007). Polyculture carries risks, such as the risk of transfer of endemic PstDNV from *P. monodon* to *L. vannamei* at the larval stage when rearing of captured *P. monodon* and exotic specific pathogen free (SPF) *L. vannamei* in Asian shrimp hatcheries. Also, *Macrobrachium rosenbergii* nodavirus (MrNV) can infect larvae of *P. monodon*

and *Fenneropenaeus indicus* causing high mortality (Ravi *et al.*, 2009), despite not causing mortality in challenged juvenile shrimp of the same two species (Sudhakaran *et al.*, 2006).

About 20 shrimp viruses have been described, some with subtypes differing in virulence, but only a few pose serious threats, and serious pathogens differ according to shrimp species. WSSV causes the greatest production losses, and it is lethal to all cultured species (Flegel, 2006a). Yellow head virus (YHV) causes serious mortalities in *P. monodon* (Boonyaratpalin *et al.*, 1993) and *L. vannamei* (Senapin *et al.*, 2010), but there are five or six subtypes and the most virulent type (YHV-1) only causes serious disease in Thailand (Wijegoonawardane *et al.*, 2008). PstDNV causes high mortality in *L. stylirostris* and stunted growth in *L. vannamei*, but has little effect on *P. monodon* (Withayachumnankul *et al.*, 2006). Most commercial stocks of *L. vannamei* are now tolerant to TSV, and PstDNV does not usually affect PL in rearing ponds. The serious viral pathogens for *L. vannamei* are WSSV, YHV Type-1 and IMNV, and for *P. monodon*, WSSV, YHV Type-1 and Laem-Singh virus (LSNV).

All these viruses exist in their shrimp and other crustacean hosts in active states, in company with other viruses, with or without visible signs of disease. A non-disease state can be converted to a disease state by various stress triggers. The first consequence arising from these facts is the possibility of transferring known (or unknown) exotic viruses to new locations together with exotic shrimp. The second is that known (or unknown) viruses may jump into the exotic imported shrimp from local crustaceans. Precautions must be taken to avoid these possibilities.

If a secure supply of uninfected postlarvae can be obtained for stocking shrimp ponds, the next biggest problem for farmers is to maintain strict biosecurity to prevent viral transmission from natural carriers to shrimp in rearing ponds, mostly by exclusion of potential shrimp and other crustacean carriers during pond preparation before stocking and during rearing after stocking. This can be accomplished simply by filtration and storage of water before it is used in rearing ponds. However, some farmers elect to use short-lived insecticides or disinfectants to treat water before it is used. Physical barriers (e.g. low fences) are often used to limit crab entry over land. Recent unpublished work in Thailand indicates that insects may sometimes be shrimp virus carriers, suggesting that ponds should be completely covered, when possible, with fine netting (i.e. equivalent to mosquito netting) to exclude insects. This has the added advantage of also excluding moribund shrimp dropped by birds from nearby outbreak ponds.

By comparison to viral pathogens, work on control of bacterial pathogens of shrimp has been less intensive and has focused mainly on farm management practices related to control of the environment in hatchery tanks and

rearing ponds. Much of this has been focused on the use of probiotics and immunostimulants. As predicted (Flegel *et al.*, 2008), development of rapid and specific diagnostic methods for major shrimp pathogens has improved steadily in the past decade. Since the reviews up to 2005 (Flegel, 2006a, 2008), more pond-side immunodiagnostic strips have been developed (Sithigorngul *et al.*, 2007) for pathogen confirmation at the prepatent or outbreak level of infection. For carrier states, more isothermal nucleic acid amplification methods have been developed for use with electrophoresis (Mekata *et al.*, 2006) or with lateral flow diagnostic strips (Jaroenram, Kiatpathomchai and Flegel, 2009). Offering test specificity and sensitivity equivalent to nested polymerase chain reaction (PCR) methods but lacking of the requirement for an expensive PCR machine, these isothermal methods provide the opportunity for more widespread application. Despite these new opportunities, more training and extension work is required to bring them to the farm level. A good model of how to achieve this can be seen in the Australian Center for International Agricultural Research (ACIAR) project (FIS/2002/075) on application of PCR for improved shrimp health management in the Asian region (Walker and Subasinghe, 2005).

In the wider application and improvement in shrimp biosecurity, much has been achieved by the implementation of good aquaculture practices (GAP), particularly via government extension workers and shrimp farmer associations, but there is still a need for more training and extension work as exemplified by the ACIAR project mentioned above. For transboundary movement of living crustaceans for aquaculture, the major problem is not with regulations but with aquaculture practitioners who ignore the regulations. A very recent example is the case of IMNV outbreaks in Indonesia (described above) initiated by illegal shrimp imports from Brazil. Clearly, laws are not enough, and there has been insufficient education to achieve a situation where everyone in the shrimp aquaculture industry believes that such activities are socially, morally and economically unacceptable.

Turning to the application of new technologies such as probiotics, immunostimulants and vaccines, there has been little change in the situation since 2005 (Flegel *et al.*, 2008). Despite the widespread use of probiotics and to a lesser extent immunostimulants in shrimp farming, there have been no published results from large-scale field trials to prove by statistical analysis that they are really effective. Field trials and more research are also needed on quorum sensing control of bacterial pathogens (Van Cam *et al.*, 2009). For so-called shrimp “vaccines” based on heterologously produced viral coat proteins, inactivated viral preparations, shrimp viral binding proteins (Ongvarrasopone *et al.*, 2008) and DNA “vaccines” (Ning *et al.*, 2009), the mechanism of protection is still unknown. Based on what is known of shrimp immunity (Flegel and Sritunyalucksana, 2010), the mechanisms are unlikely to be the same as those associated with vaccines used in fish and other vertebrates. Other recent discoveries include the efficacy of using double-stranded RNA (see Robalino *et al.* 2007 for a review) and egg

yolk antibodies (passive immunity) (Lu *et al.*, 2008) to protect shrimp from viral infections. So far, reports of all these new technologies have been based on laboratory trials, and further tests are needed to determine whether they will be efficacious in large-scale commercial applications. For more details on these technologies, readers may consult a number of recent reviews (e.g. Robalino *et al.*, 2007; Flegel and Sritunyalucksana, 2010). Very recently, it has been proposed that viral inserts in the shrimp genome may be the basis of a new type of heritable immunity (Flegel, 2009). If this proves correct, it will fundamentally change the process for selection of viral-resistant shrimp stocks.

Finally, work on shrimp molecular epidemiology has been focused largely on comparison of geographic isolates of infectious hypodermal and hematopoietic necrosis virus (IHHNV) (Tang and Lightner, 2006), TSV (Tang and Lightner, 2005), WSSV (Pradeep *et al.* 2008) and YHV (Wijegoonawardane *et al.*, 2008) and less on the more practical aspects of dynamics and risks of spread in farming systems. Work on molecular ecology (i.e. metagenomics) and biochemical engineering to control the microbial dynamics in shrimp ponds and hatchery tanks has been relatively neglected.

Disease diagnostic methods: developments, gaps in knowledge and needs

Rapid disease diagnosis is crucial to the sustainability of aquaculture, and rapid progress in biotechnology over the last decade has enabled the development and improvement of a wide range of immunodiagnostic and molecular techniques (Cunningham, 2004; Adams and Thompson, 2006, 2008), and reagents and kits have become more widely available. In recent years, methods developed for clinical and veterinary medicine have been adapted and optimized for use in aquaculture. Despite this, identification of certain pathogens is difficult to achieve, and some of the methods developed are too complicated to implement and interpret. Traditional methods of pathogen isolation and characterization tend to be costly, labour intensive, slow and may not give a definitive diagnosis. For many rapid methods, live and dead pathogens cannot be distinguished; therefore, enrichment methods and the use of live/dead kits are useful supplementary methods (Vatsos, Thompson and Adams, 2002). Interpretation of results using rapid methods should be considered with other clinical evidence. The OIE *Aquatic Animal Health Manual* (OIE, 2911b) includes standardized methods for the identification of notifiable pathogens, but for those diseases that are not included, there are no set standards. Commercial reagents and kits (Adams and Thompson, 2008) provide specific and sensitive standardized methods, but a full range of reagents or kits is not available for use in aquaculture. The cost, speed, specificity and sensitivity of assays are all extremely important to end-users. Many of the new technologies require specialized equipment and highly skilled staff, and few of the existing methodologies are suited to field testing or use in rudimentary laboratories.

Immunodiagnostic methods currently used, such as immunohistochemistry (IHC), the fluorescence antibody test (FAT) and indirect fluorescence antibody test (IFAT) enable rapid specific detection of pathogens in tissue samples without the need to first isolate the pathogen. IHC is an extension of histology, while FAT/IFAT is a more rapid, sensitive procedure. Other antibody-based methods, such as the enzyme linked immunosorbent assay (ELISA), have also been developed for use in aquaculture (Adams and Thompson, 1990). ELISA allows high throughput, and automated equipment is available, but is less sensitive than IHC and IFAT. ELISA can also be used for serology, although it has not yet been validated for any bacterial diseases in fish. Serology, however, effectively detects fish viruses, such as KHV (Adams and Thompson, 2008). Recently, lateral flow technology is widely used in clinical and veterinary medicine (Bai, *et al.*, 2006) and has been developed for use in aquaculture (Adams and Thompson, 2008). It is very rapid and sensitive, and can be used as a pond-side test. Commercially available kits for infectious salmon anemia virus (ISAV) were recently independently evaluated (Carauel *et al.*, 2010) against other methodologies (culture, IFAT, reverse transcriptase-PCR (RT-PCR) and quantitative RT-PCR (qRT-PCR)) and were found to have the highest operational specificity. This technology is simple to use, rapid (with results in less than 10 min), cheap to perform and does not require skilled operators or expensive equipment.

Molecular technologies for the detection of fish pathogens (Cunningham, 2004; Adams and Thompson 2006, 2008) generally have the highest sensitivity in detecting low numbers of micro-organisms and those that are difficult to culture. They can identify species (Pourahmed, 2008) and individual strains, and differentiate closely related strains (Cowley *et al.*, 1999). There are many variations of PCR, including nested PCR, random amplification of polymorphic DNA (RAPD), RT-PCR, reverse cross blot PCR (rcb-PCR) and RT-PCR enzyme hybridisation assay (Cunningham, 2004). Colony hybridization rapidly identifies *Vibrio anguillarum* in fish, and detects both pathogenic and environmental strains (Powell and Loutit, 2004). Real-time quantitative PCR (qRT-PCR) offers quantification and high sample throughput. Real-time PCR methods have recently been developed for a variety of significant fish bacterial pathogens (Bacázar *et al.*, 2007), and many viral pathogens (Hick and Whittington, 2010). Polygenic sequencing of specific genes following PCR identifies some pathogens where differentiation of closely related species is difficult, such as the three different genes necessary to classify some fish mycobacteria (Pourahmed, 2008). Multiplex PCR permits the simultaneous detection of *Aeromonas hydrophila*, *A. salmonicida* subsp. *salmonicida*, *Flavobacterium columnare*, *Renibacterium salmoninarum* and *Yersinia ruckeri* (Altinok, Kapkin and Kayis, 2008), and pathogens in yellowtail (*Seriola lalandi*) and sea bass (*Dicentrarchus labrax*) (Amagliani *et al.*, 2009). Loop-mediated isothermal amplification (LAMP) is faster and simpler and can detect bacterial, parasitic and viral fish pathogens. It is faster and more sensitive than conventional PCR (Notomi *et al.*, 2000) and can be performed in 90 minutes, without the use of a thermocycler, making it

suitable as a field test (Soliman and El-Matbouli, 2005). LAMP uses autocycling strand displacement DNA synthesis, using *Bst* DNA polymerase and at least four specially designed primers (two inner and two outer) to recognize six distinct sequences on the template DNA (Notomi *et al.*, 2000). The reaction time can be reduced using two further primers. Products of LAMP amplification can be visualized by eye with the addition of SYBR Green I to the mixture, or can be detected by photometry due to magnesium pyrophosphate turbidity. Some commercial LAMP kits use an enzyme substrate system to visualize the reaction on a membrane.

Fifteen fish pathogens have been discriminated using microarray technology, and several groups are working on assay development. The method involves hybridizing samples of DNA fragments (amplicons), amplified by PCR, on to specific DNA detector fragments spotted onto a solid support. A large number of DNA spots from different pathogens can be included on a single slide, allowing multiplexing for different pathogens. The method is highly sensitive, specific, has high throughput capacity, reduces costs and increases the speed of diagnosis, but is in its infancy in aquaculture (Kostić *et al.*, 2008).

Prudent and responsible use veterinary medicines

Antimicrobials

As in other animal production sectors, veterinary medicines (particularly antimicrobial agents) are used in aquaculture during both production and processing, mainly to prevent and treat bacterial diseases. Antimicrobial agents are biologically active at very low concentrations, demanding their prudent use. Of their possible adverse effects, the most important is clinically significant resistance in target bacteria, and therefore their treatment can have no beneficial effect and is imprudent. Similarly, their routine prophylactic use, particularly in hatcheries and when the cause of disease is not bacterial, is uneconomic and unjustifiable.

The enormous gains in aquaculture production capacity that have been achieved globally during the past 30 years would not have been possible without the use of veterinary medicines. All antimicrobial agents in use in aquaculture are also used in human or veterinary medicine. There are no antimicrobial agents that have been specifically developed for aquaculture use, and simple economic considerations suggest that this will always be the case (FAO, 2012b).

The *Aquatic Animal Health Code* (OIE, 2011a) recognizes that antimicrobial agents are essential for treating, controlling and preventing infectious diseases in aquatic animals. While continued access to antimicrobials is a priority, direct and indirect adverse effects must be considered.

Direct adverse effects result from the agent being in the environment of the production facility or in the marketed product. Environmental direct effects

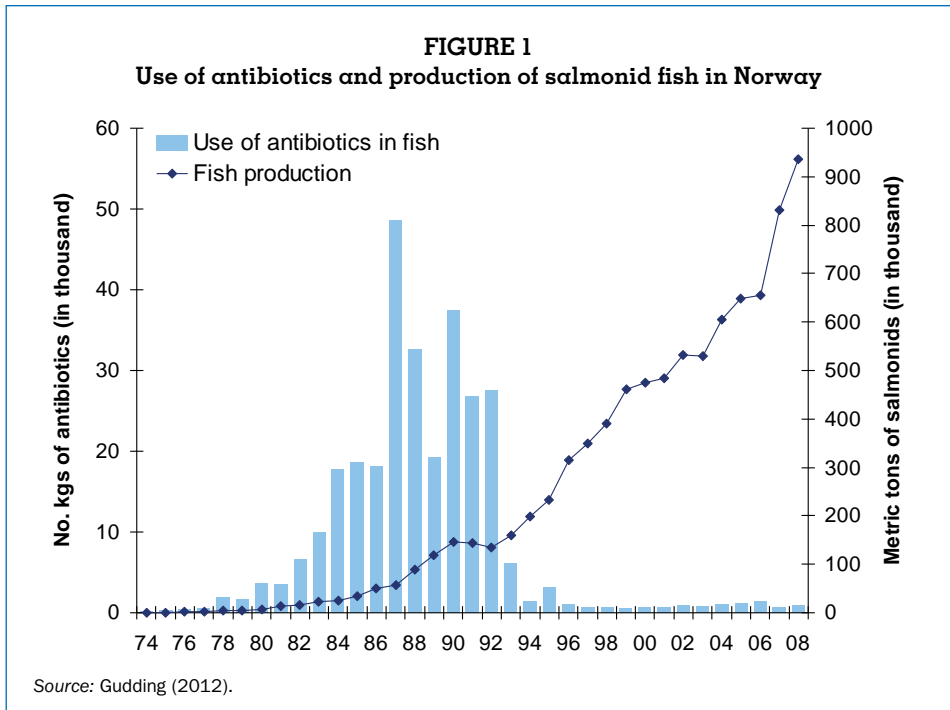
are probably small scale, local and short term. Despite a lack of reports on adverse effects on human health from agents in aquacultural products, their presence has a major influence on market acceptability and on the economics of aquaculture. In the last decade, there have been major improvements in control of residues by regulatory agencies, but a major problem relating to residues is the lack of agents with marketing authorizations (MA) for use in aquaculture. For example, there are no agents with MA for application to shrimp culture. Also, many producer countries regulate agent use by banning unacceptable agents rather than by authorizing usable agents. The setting of maximum residue levels (MRL) and recommended withdrawal times (WT) has been strongly linked to the granting of MA. A major consequence of the lack of MA is the lack of specific evidence-based regulatory MRL and WT values. MRL values can be set by processes that do not require the simultaneous granting of an MA. For example the Codex Alimentarius has set an MRL for oxytetracycline in shrimp. Knowledge of WT is necessary for the prudent use of these agents in aquaculture, and serious consideration should be given to the setting of generic WT. Although these would be conservative, they would provide some much needed guidance.

Indirect adverse effects result from the potential of antimicrobials to selectively enrich resistant variants, which must be considered in two contexts: aquatic animal therapy and human therapy. In aquatic animal health, the main problem is resistance in the bacterial target of therapeutic administration, and ample data show that the agents used in aquaculture have caused significant resistance in target bacteria. Attempts to treat an infection by a resistant bacterium are bound to fail. In human health, although resistance in agents in aquaculture may transfer to human pathogenic bacteria, there is no evidence of this. The frequency of transferable gene-encoded resistance in human pathogens may be highly complex, and limit the applicability or value of formal risk analysis. Three factors must be recognized: (i) resistant bacteria in aquaculture may derive from contamination of the water supply by land-derived resistant strains; (ii) resistant bacteria may occur in aquaculture products from postharvesting contamination; and (iii) for many of the diseases of humans associated with the consumption of fish, antimicrobial therapy is not recommended and, therefore, the occurrence of resistant variants has no relevance.

In most cases, there are no validated test protocols to determine the clinical resistance or sensitivity of target bacteria. Three largely unresolved problems include: (i) harmonization of the test protocols, (ii) setting of interpretive criteria and (iii) development of the laboratory infrastructure to perform the tests.

Vaccines

The use of antimicrobials may be significantly reduced by the use of vaccines, when possible (see Figure 1) (Gudding, 2012). Vaccination has been successful in prevention of bacterial diseases such as vibriosis, furunculosis, yersiniosis, edwardsiellosis, pasteurellosis and other Gram-negative bacterial infections.



Streptococcosis and lactococcosis, caused by Gram-positive bacteria, are preventable by vaccination, but vaccination against intracellular bacteria like *Piscirickettsia* has not been achieved. Prevention of viral diseases has been less successful, with vaccines against infectious pancreatic necrosis virus (IPNV), infectious salmon anaemia virus (ISAV) and other viruses giving some, but not acceptable protection. Vaccines have been developed for diseases of several fish species (i.e. *Salmo salar*, *Oncorhynchus mykiss*, *Dicentrarchus labrax*, *Sparus aurata*, *Ictalurus punctatus*). They are administered by injection, with or without adjuvants, and by immersion. Adjuvants are added when a strong immune response is required, as with furunculosis and most viral diseases. Oral administration of vaccines is also possible, but gives inferior results. Most vaccines are inactivated products. Live vaccines have been developed against diseases which cannot be treated by bacterins, such as a vaccine against *Edwardsiella ictaluri*. Molecular vaccines are available, and a DNA-vaccine has been licenced for use against infectious hematopoietic necrosis (IHN) in salmonids.

Immunoprophylaxis contributes to sustainability of aquaculture by reducing disease prevalence, use of antibiotics, prevalence of antibiotic-resistant bacteria, and prevalence of residues in aquacultural products. The main side effects are lesions using adjuvanted vaccines, which may be a welfare problem and may cause melanosis at the lesion site, reducing marketability. The only effective method of vaccinating small fish is by immersion or oral administration, and inactivated vaccines may be non-protective because of low antibodies

and insufficient cellular immunity. Consequently, live vaccines or recombinant vaccines for immersion or oral administration might be the only type of vaccine giving acceptable protection.

Live vaccines can be developed by attenuation of pathogenic bacteria by passages through media or tissue culture. Addition of rifampicin to the medium has been successful for attenuation of Gram-negative bacteria. Use of low-pathogenic micro-organisms as live vaccine gives protection against bacterial kidney disease (BKD) (*Renibacterium salmoninarum*). Genetic modification has been used for inactivated vaccines by insertion of genes into vectors for large production of virulence factors. Development of live vaccines can be achieved by deletion of virulence factors, making mutants which are safe to use. As vaccines for aquatic animals are released into the environment, live vaccines may pose risks. Vaccines may be developed against fungal diseases and parasites, such as epizootic ulcerative syndrome (EUS) and salmon lice (*Lepeophtheirus salmonis*), but not in the near future. Development of such vaccines will allow antibiotics and chemotherapeutants to be reserved for emergencies.

Health management tools: the manufacturer's point of view

Several types of veterinary medicines exist and are registered for aquatic species (Wardle and Boetner, 2012). These include the following:

- Vaccines – These are products that are directly or indirectly produced from the pathogen and administered to the animal to elicit a specific (lasting) immune response for the prevention of a range of mainly bacterial and viral diseases. Vaccines are widely used in intensive farming conditions world-wide. They are supplied as immersion, oral or injection preparations. Vaccines provide pathogen-specific disease prevention.
- Antibiotics – For treatment and cure of bacterial infections in fish.
- Antiparasitic products in feed or bath – For the treatment of external parasites (e.g. sea lice, *Benedenia*).
- Antifungal disinfectants – For eggs and infected fish.
- Immunostimulants designed to enhance the natural non-specific immune parameters of fish and shrimp to defend against mild infections and environmental stress that might trigger outbreaks.

The manufacture and production of medicines and health products for aquatic animals follows a tedious process that requires full engagement with producers, veterinarians and aquatic animal health professionals, feed companies, and regulatory bodies. The work transcends quality assurance programmes, best practices schemes to ensure that products are both efficacious, as well as safe for consumers, the fish farmers, the fish and the environment. The cycle for developing and managing a veterinary medicine for aquaculture follows a lengthy process starting from the identification of a disease and its underlying cause. The next steps involve finding a cure. The discovery of a compound that is effective against a pathogen leads to the product development phase. This

requires a high level of investment and expertise, and a great deal of work is undertaken with the active compound or the vaccine antigen to document its quality, safety and efficacy, addressing the regulatory requirements and above all, to ensure that control systems are in place to guarantee the same product standards throughout. The cost and complexity of the work means that for pharmaceutical products destined for use in aquaculture, the active ingredients will usually be registered for other animal species or other larger markets than aquaculture as well. Vaccines, however, are specifically developed and registered for aquaculture. The registration package covers all aspects of the product, and most of the data generated must come from the final product formulation that will be, or is intended to be placed on the market. The data cannot be extrapolated from other similar formulations or manufacturers.

Development documentation is generated covering the manufacturing processes and procedures, quality control checks and validated pass criteria for each stage of the manufacturing process. Compliance with the process and procedures is key to ensuring the consistency and reliability of the medicine being produced. This is critical for the on-farm performance, but even more importantly, to ensuring that the fish is safe and wholesome for human consumption.

Before an active ingredient can be developed into a medicine, a number of issues need to be evaluated and fully understood. These include: pharmacological properties of the active ingredient, toxicity issues, mutagenicity, carcinogenicity studies, immunotoxicity, microbial properties of residues, target animal safety and environmental issues.

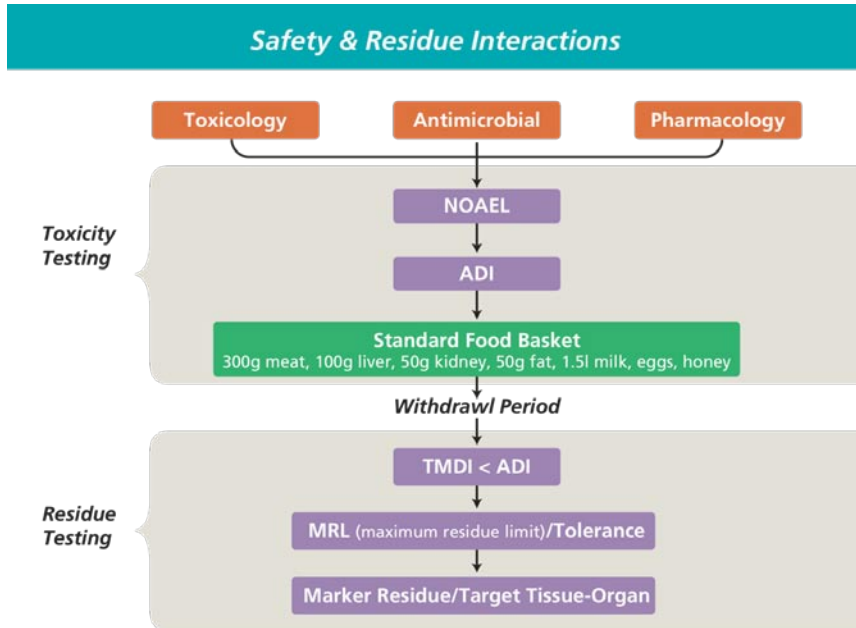
Figure 2 shows that the toxicological/safety development work allows an acceptable no observed adverse effect level (NOAEL) to be established. The acceptable daily intake (ADI) is then calculated from this level. This establishes how much of the active ingredient or its metabolites can be consumed without posing a risk to the consumer. The ADI is then compartmentalized between the components of the “standard food basket”, with fish being included in the daily meat ration (300 g). This is used to establish the maximum residue limit (MRL) that can be accepted in fish. This is measured in the edible tissues, which are considered to be the fillet, i.e. muscle with normal proportion of skin attached.

Once an MRL is established, the manufacturing company must demonstrate that the formulated product used under the recommended conditions will deplete to ensure that the active compound and or its metabolites will be at levels lower than the MRL after the defined withdrawal period has elapsed.

The implementation of the human food safety procedures is important both in the country where the fish are produced as well as in the country of destination for exported products. International (i.e. Codex Alimentarius) and national requirements have to be strictly followed to ensure that safety requirements

FIGURE 2

Diagram describing the steps and procedures required to establish an acceptable withdrawal time for a pharmaceutical medicine. (NOAEL – no observed adverse affect level; ADI – acceptable daily intake; TMDI – total maximum daily intake; MRL – maximum residue limit)



Source: Wardle and Boetner (2012).

of the importing countries are fully met. These are usually enforced by port of entry inspections. When a farm uses a registered medicine in the correct way and follows the guidelines for withdrawal, they can be confident that the use of the product does not result in a product that contains a harmful residue or causes any disruptions in the trade of foods. This approval process ensures that the medication used is safe for the consumer, the environment, the user and of course, for the fish, that it is efficacious and is produced to an approved quality standard.

Once the medicine has been approved, the manufacturing company continues to bear the responsibility for the marketing and technical support for the product. The pharmaceutical company has to follow specific pharmacovigilance responsibilities to monitor any unexpected problems (adverse reactions) which may arise with the use of the medicine in the field. In addition to the above responsibilities, the manufacturer plays an important role in supporting veterinarians and aquatic animal health professionals and farmers in achieving the best performance from the medicines that they use and rely on to achieve their production goals.

Food-borne human infections from aquatic products

Food safety also includes the elimination of food-borne human infection from aquatic products. While enterobacterial agents such as *Salmonella* do occur in fishery products, such contamination is uncommon. Non-typhoidal salmonellae cause an estimated 1.4 million illnesses in the United States of America each year, but only about 5 percent of *Salmonella* infections in the United States of America are due to seafood. Analysis of 11 312 imported and 768 domestic seafood in the United States of America during 1990–1998 revealed that 10 percent of imported and 2.8 percent of domestic raw seafood was positive for *Salmonella* and the overall incidence was 7.2 percent for imported and 1.3 percent for domestic seafood. *Salmonella* has been isolated from freshwater catfish ponds (5 percent prevalence) in the United States of America and from eel culture ponds in Japan (21 percent prevalence), and it has been found in 16 percent in shrimp and 22.1 percent in mud/water in Southeast Asia, and in 30 percent of cultured United States channel catfish and 50 percent of Vietnamese catfish.

Fishborne zoonotic trematodes (FZTs) are an emerging food safety issue in many Asian countries (Tran *et al.* 2009, Phan *et al.* 2010), particularly those with large aquaculture sectors, and are also receiving increased attention by countries outside Asia (e.g. the United States of America and Europe). The WHO and the FAO have estimated that FZTs infect more than 18 million people, with the global number of people at risk estimated to be greater than 500 million, mainly in Asian countries. Depending on the trematode species, the adult parasites infect the liver or intestine of the final host, which include humans, cats, dogs, pigs and other mammals. The adult fluke produces eggs which are excreted by the host and may contaminate the aquatic environment, where they infect snail species in which further development and multiplication occur (Skov *et al.* 2009). Free-swimming cercarial parasites are released from the snail and penetrate into the fish. The final host is then infected by eating raw or prepared fish containing infective metacercarial parasites.

Common in Viet Nam, FZTs are a significant risk to public health and safety of fish products. There has been a 9.3 fold increase in freshwater fish production in Southeast Asia, including Viet Nam, in the last few decades, with increased concern about the role of aquaculture in transmission of FZTs and a need to prevent or control the transmission of the parasites. The project Fishborne Zoonotic Parasites in Viet Nam (FIBOZOPA; <http://fibozopa2.ria1.org>) addresses this important public health and food safety problem in aquaculture. It works with research institutions, universities and government institutions within human and animal health, aquaculture and natural science to prevent FZTs in Vietnamese aquaculture. There is great variability in the prevalence and intensity of FZT metacercariae starting in fish nurseries, depending on the type of aquaculture and its location. In high-intensity culture (e.g. pangasiid catfish in southern Viet Nam), FZT metacercarial prevalence is generally less than 5 percent, whereas in

more extensive ponds (e.g. household-based carp ponds in northern Vietnam) infection rates are less than 90 percent. The parasites are mainly intestinal flukes, in particular *Haplorchis* spp. In rural Viet Nam, food fish are often taken directly from ponds, rivers and lakes, so it is important to prevent FZT infection at the preharvest level. For exported fish species, e.g. pangasiid catfish, FZT prevalence must be low enough to meet the food safety standards of importing countries. As prolonged freezing at -20 °C kills all parasites in fish products, exported frozen fish products are safe for human consumption.

Less attention has been given to animals as reservoir hosts in the epidemiology of FZTs than to humans. A FIBOZOPA study of an aquaculture community found farmers had only 0.6 percent prevalence of FZTs, but fish from aquaculture ponds had very high prevalences. Cats, dogs and pigs had FZT infections of 48.6 percent, 35.0 percent and 14.4 percent, respectively, with seven species of adult zoonotic flukes. Domestic animals are therefore reservoir hosts for FZTs (Nguyen *et al.* 2009), and drug treatment of the humans alone will not prevent transmission of FZTs to cultured fish.

Snails are critical in control and prevention of metacercariae in fish, but extensive surveys of intermediate host snails in fish ponds and other habitats have not revealed snails infected with *Clonorchis sinensis*, while several species (*Melanooides tuberculata*, *Sermyla riquetii*, *Thiara scabra*) were infected with different species of intestinal trematodes.

The potential risks for parasite transmission have been assessed in epidemiological studies in nurseries and grow-out ponds. Hazards identified include poor water quality, presence of snails, faecal contamination from infected animal and human reservoir hosts, and the use of untreated animal manure as pond fertilizer. To address these risks, an intervention study at pond level has been introduced in Viet Nam. The interventions are low cost and can be easily implemented and managed by farmers, building on their existing skills with only limited training. The programme can be integrated into general programmes on biosecurity and best management practices (BMPs) related to aquatic animal health management and to overall good farm management. As a large amount of the fish that are eaten in rural areas do not pass through a processing plant, the pond-level food safety interventions are important for the public health in the rural areas.

Use of specific pathogen free (SPF) stocks

Since the publication of the *Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000*, a major revolution in shrimp cultivation has occurred, with the widespread adoption of domesticated and genetically improved whiteleg shrimp (*Litopenaeus vannamei*) as the cultivated species of choice. This has fulfilled one of the recommended interventions of the Bangkok Declaration (i.e. “developing and utilising improved domestication and broodstock management

practices and efficient breeding plans to improve production in aquatic animals”). The resulting change in shrimp aquaculture production output from approximately 1 million tonnes in 2004 to 3.2 million tonnes (more than triple) in 2007 (*FishStat plus*, FAO, 2010a) is a testament to how effective such interventions can be. On the other hand, it should not be assumed that this increase in production was due solely to introduction of the new stocks, since it was accompanied by a suite of other advances, particularly regarding biosecurity and disease control.

Use of SPF shrimp in biosecure hatcheries (i.e. hatcheries that exclude free viruses and their carriers) can virtually eliminate viral transmission risk via postlarvae used to stock rearing ponds. Biosecurity includes the need to cover outdoor nursery tanks to exclude potential insect carriers. Use of locally captured wild shrimp as broodstock for postlarval production to stock rearing ponds is always accompanied by a high risk that they will carry one or more known or unknown viruses without showing signs of infection, and that they will transmit these viruses to their offspring in shrimp hatcheries. Using captured broodstock tested for known viruses and spawned individually for individual larval rearing in biosecure facilities can reduce this viral transmission risk, but never to zero. That is the reason for mandatory development of domesticated SPF stocks for any shrimp species targeted for sustainable industrial production. Another risk for hatcheries is the continued use of live feeds. A long-term target should be to remove all live feeds from broodstock and larval diets and to substitute them with defined, dried feeds that are free of shrimp pathogens. Targets for replacement include such things as live algal feeds, *Artemia*, polychaetes and squid meat.

The paramount need for SPF domesticated shrimp stocks in sustainable shrimp aquaculture is based on a prime biosecurity issue for shrimp and other crustaceans that differs markedly from vertebrate species. The latter are often capable of clearing viral pathogens from their systems during suitable periods of quarantine. By contrast, crustaceans often carry (and share among species) one or more viral pathogens (even lethal ones) as persistent infections for long periods (up to a lifetime) without showing any gross signs of disease. Although these viruses are often present at low levels, they are active and can be passed on to other naïve shrimp or other crustaceans that may suffer lethal infections. They can also be passed from the broodstock to their grossly normal larvae and postlarvae, either naturally or in a hatchery, and this may lead to subsequent disease outbreaks in rearing ponds stocked with the infected postlarvae. This propensity of grossly normal crustaceans to carry known and unknown viral pathogens means that special precautions are needed whenever living crustaceans destined for aquaculture are translocated over large geographical distances, and especially to areas outside their natural range (Flegel, 2006c). Unfortunately, disregard for this propensity has resulted in several major shrimp virus epidemics (epizootics), most notably for *Penaeus stylirostris* densovirus

(PstDNV) (formerly called infectious hypodermal and hematopoietic necrosis virus or IHNV) in the blue shrimp (*Litopenaeus stylirostris*) and the whiteleg shrimp (*L. vannamei*) in the Americas, WSSV in all cultivated shrimp in Asia and the Americas (Flegel, 2006b), Taura syndrome virus (TSV) in *L. vannamei* cultivated in Asia (Nielsen *et al.*, 2005) and most recently, infectious myonecrosis virus (IMNV) in *L. vannamei* cultivated in Indonesia (Senapin *et al.*, 2007).

Every country should be wary of importing exotic crustaceans of any kind for aquaculture without going through the recommended risk analysis and quarantine procedures, combined with tests for unknown viruses that might be a danger to local species (Flegel, 2006c). Risk analysis is necessary to assess emerging threats from new or exotic species (Arthur *et al.*, 2009). These biosecurity measures should be applied even to exotic domesticated stocks that are SPF for a list of known pathogens. To reduce risks to the minimum, any country that imports exotic stocks for aquaculture should invest in establishment of local breeding centers comprised of properly vetted stocks that could be used for ongoing supply of broodstock and postlarvae to stock cultivation ponds. This would avoid the continual risk of importing unknown pathogens that might be associated with continuous importation and direct use of exotic stocks, even from a foreign breeding center that produces SPF stocks.

An allied issue concerns the co-cultivation of one shrimp species with one or more other shrimp species or with other crustacean species. For example, rearing of captured *Penaeus monodon* and exotic SPF *L. vannamei* in an Asian shrimp hatchery would be a good way to transfer endemic PstDNV from *P. monodon* to *L. vannamei* at the larval stage. In another example, it has recently been shown that *Macrobrachium rosenbergii* nodavirus (MrNV) (the cause of white muscle disease in *M. rosenbergii*) can infect larvae of *P. monodon* and *Fenneropenaeus indicus* and result in high mortality from white muscle disease (Ravi *et al.*, 2009), even though it does not cause mortality in challenged juvenile shrimp of the same two species (Sudhakaran *et al.*, 2006). In summary, there are good reasons to avoid mixed cultures of shrimp or other crustaceans unless one is very, very certain that negative viral interchanges are not possible.

Living modified organisms/genetically modified organisms

The rise of molecular genetics and the development of biotechnology are hallmark scientific achievements of the past three decades. Advances in biotechnology offer the potential for significant improvements in human well-being, so long as adequate measures are taken to safeguard human health and the environment. These concerns were recognized by those who negotiated the Convention on Biological Diversity (CBD), signed by most countries of the world in 1992. In Article 19.3 of the CBD, the Contracting Parties agreed to consider the need for developing appropriate procedures to address the safe transfer, handling and use of any living modified organism (LMO) resulting from application of biotechnology that may have an adverse effect on the conservation and sustainable use of

biodiversity. The Cartagena Protocol on Biosafety, a supplementary agreement to the CBD adopted in 2003, governs the movements of LMOs from one country to another. A living modified organism (LMO) is defined in the Cartagena Protocol as any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology (UNEP, 2009). LMOs are generally considered to be the same as genetically modified organisms (GMOs). While different classes of organisms have been included in the term GMO – including organisms modified by gene transfer, chromosome set manipulation, and interspecific hybridization – discussion has focused upon transgenic organisms; hence, this contribution focuses upon transgenic aquatic organisms. A transgenic fish or shellfish bears within its chromosomal DNA a gene construct – i.e. a transgene, a gene whose expression is under novel regulation – that was introduced by human intervention. The benefits, risks, and management of risks posed by aquatic GMOs are described below.

Benefits posed by aquatic GMOs

A number of different traits have been targeted for genetic improvement via gene transfer, including growth rate, freeze resistance, disease resistance, phytate utilization, reproductive confinement and completion of biosynthetic pathways (Table 2). Most transgenic lines have not been subject to the generations of

TABLE 2
Examples of gene transfers in fish targeting aquaculture production traits

Targeted trait	Species	Transgene	Reference
Rapid growth	Atlantic salmon (<i>Salmo salar</i>)	Growth hormone	Du <i>et al.</i> , 1992
	Coho salmon (<i>Oncorhynchus kisutch</i>)	Growth hormone	Devlin <i>et al.</i> , 1994
	Common carp (<i>Cyprinus carpio</i>)	Growth hormone	Hinitz and Moav, 1999
	Mrigal carp (<i>Cirrhinus cirrhosus</i>)	Growth hormone	Venugopal <i>et al.</i> , 2004
	Mud loach (<i>Misgurnis myzolepis</i>)	Growth hormone	Nam <i>et al.</i> , 2001
	Nile tilapia (<i>Oreochromis niloticus</i>)	Growth hormone	Rahman <i>et al.</i> , 2001
	Disease resistance	Channel catfish (<i>Ictalurus punctatus</i>)	Cecropin
Grass carp (<i>Ctenopharyngodon idella</i>)		Lactoferrin	Mao <i>et al.</i> , 2004
Freeze resistance	Atlantic salmon	Antifreeze polypeptide	Hew <i>et al.</i> , 1999
	Goldfish (<i>Carassius auratus</i>)	Antifreeze polypeptide	Wang <i>et al.</i> , 1995
Phytate utilization	Nile tilapia	Phytase	Kemeh, 2004
Reproductive sterility	Rainbow trout (<i>O. mykiss</i>)	Gonadotropin releasing hormone anti-sense mRNA	Uzbekova <i>et al.</i> , 2000
		<i>zBMP2</i> , a dorsoventral developmental patterning gene	Thresher <i>et al.</i> , 2009
Vitamin C synthesis	Rainbow trout	L-gulonolactone oxidase	Krasnov, Pikanen and Molsa, 1999

breeding needed to develop a homozygous line stably expressing the transgene. However, development of some growth hormone (GH)-transgenic lines is well advanced, and efforts to commercialize them are ongoing, including Atlantic salmon (*Salmo salar*) in the United States of America (Fletcher *et al.*, 2004), tilapia in Cuba, and common carp in China (Wu, Sun and Zhu, 2003). With the prospect of improved production efficiency, it is not surprising that some aquaculturists want to produce GH-transgenic fish commercially.

Risks posed by aquatic GMOs

Commercial aquaculture operations have a routine, often significant escape of fish through equipment failures, handling or transport operations, predator intrusion, storm damage or other mechanisms. Although farm operators attempt to prevent escapes by upgrading confinement systems, installing predator deterrent devices, and other actions, it still must be assumed that escapes will occur. Escape of cultured fish into the accessible ecosystem and ecological or genetic interactions with local intraspecific and interspecific populations pose environmental concerns (McGinnity *et al.*, 2003). Ecological concerns focus upon competition for space and food resources and direct predation (Gross, 1998). Genetic concerns include the potential breakdown of locally adapted traits through interbreeding and introgression, and range up to replacement of native stocks by cultured stocks (Saegrov *et al.*, 1997). Such concerns are posed by the prospect of producing transgenic fish in aquaculture, with additional unknowns posed by possible effects of the transgene.

Ecological risk assessment for transgenic fish is based upon case-by-case assessment of the host species, transgene, site of genomic integration, and receiving ecosystem (Kapuscinski and Hallerman, 1990). Potential hazards at issue are illustrated by empirical studies with GH-transgenic fishes. To support their rapid growth, GH transgenics require more energy, and hence will feed more actively than non-transgenic fish; for example, increased feeding rate, feeding competition and willingness to feed in the presence of a predator have been observed in Atlantic salmon (Abrahams and Sutterlin, 1999), coho salmon (Devlin *et al.*, 2004) and common carp (Duan *et al.*, 2009). The effects of introgression of a transgene into a receiving population will vary among receiving populations (Devlin *et al.*, 2001) and environmental conditions, including food availability (Devlin *et al.*, 2004), and may result in decreased demographic viability of the resulting population. Models have been developed to predict the genetic and demographic effects of interbreeding of transgenic and non-transgenic fish (Muir and Howard, 1999) but have yet to be empirically validated. General frameworks for quantifying ecological (Devlin *et al.*, 2007) and genetic (Kapuscinski *et al.*, 2007) risks have been developed. Ecological and genetic risks have not been well investigated for transgenes other than growth hormone. Further, because exact probabilities of risk are difficult or impossible to determine for all types of possible harm, it may be necessary – based on current knowledge of population genetics, population dynamics, receiving ecological communities and experience

with cultured stocks – to classify levels of concern regarding likely genetic impacts posed by cultured stocks into qualitative categories ranging from low to high.

Risk management

Under at least some circumstances, escaped transgenic fish could negatively impact accessible ecosystems and populations. The best approach for minimizing the likelihood of harm becoming realized is to minimize exposure to the hazard, in this case, escaped transgenic fish. Differences in species, production traits, receiving ecosystems and culture systems will affect the case-by-case determination of appropriate risk management measures for experimental and commercial (Mair, Nam and Solar, 2007) production systems. Risk might be managed by producing transgenic fish only under conditions of confinement; in high-risk contexts, production of transgenic fish might go forward only under conditions of strict confinement aimed at ensuring no escape of transgenic fish into the accessible ecosystem. Three non-mutually exclusive approaches to achieving confinement of aquatic GMOs include: (i) physical confinement, (ii) reproductive confinement and (iii) operations management. Achieving effective physical confinement of cultured aquatic organisms will require a combination of careful selection of production site, production system, barriers to escape of cultured organisms, and barriers to animal or human intrusion onto the site (ABRAC, 1995; Mair, Nam and Solar, 2007). Lack of reproduction would prevent loss of difficult-to-confine early life stages from the culture facility or establishment of a population of escaped transgenic fish in the accessible ecosystem. Reproductive confinement might be approached by production of monosex or triploid stocks (Mair *et al.*, 1997; NRC, 2004), although neither approach is likely to prove 100 percent effective. Transgenic approaches to reproductive confinement are under development, although progress is slow. Operations management measures are needed to: (i) ensure that normal activities of workers at the aquaculture operation are consistent with the goal of effective confinement, (ii) prevent unauthorized human access to the site and (iii) ensure regular inspection and maintenance of physical confinement systems. Combinations of risk management measures are advisable so that failure of any one measure will not lead to escape of confined stocks.

Over the past ten years, the following trends in technical advancements and development of national capacity for technology oversight have been observed. While most early gene transfer experiments targeted growth rate by introduction of growth hormone transgenes, recent work has targeted a greater range of traits, often utilizing structural genes not found in the host genome. Of relevance here, interest in promoting bioconfinement of cultured stocks led to gene transfers aimed at inducing reversible sterility (Wong and Van Eenannaam, 2008). The past ten years have seen elaboration of empirical data on risk assessment, mostly on salmonids, and to a lesser degree with model species such as medaka (Japanese ricefish, *Oryzias latipes*) and other aquaculture species such

as tilapias and carps. The range of issues posed by a proposed utilization of transgenic fish in aquaculture led to elaboration of a protocol for oversight of aquatic GMOs within a three-stage, interactive framework (Hayes *et al.*, 2007). Because all potential harms and associated pathways cannot be known and precisely predicted *a priori*, it will be necessary to update the risk analysis as knowledge accumulates using an adaptive management approach (Kapuscinski, Nega and Hallerman, 1999). The decision of whether and under what conditions production of transgenic fish would go forward will be made at the national level. Under Article 21 of the CBD and the Cartagena Protocol, signatories commit to developing and implementing policies for oversight of biotechnology. Consequently, countries including Cuba, Thailand, China, Chile and Peru are developing and implementing policy and staffing government offices that would consider applications for production of transgenic fish.

Biological invasions

Biological invasion is one area that was not addressed in the 2000 Bangkok Declaration and Strategy. The human-mediated introduction of marine species is increasingly recognized as a threat to sustainable management of marine ecosystems and the maritime economies of coastal nations (Molnar *et al.*, 2008), yet in most regions of the world, the scale and scope of marine introductions are poorly known (Carlton, 1996; Hewitt, 2002; Hewitt and Campbell, 2008). Unlike the long history of recognition of freshwater introductions, marine introductions have only been investigated over the last 40 years, during which marine and estuarine introductions have been detected worldwide (Ruiz *et al.*, 2000; Hewitt, 2003; Molnar *et al.*, 2008; Hewitt and Campbell, 2008) by literature evaluation (Carlton, 1996; Ruiz *et al.*, 2000; Rilov and Crooks, 2009) and general biodiversity surveys or targeted surveys (Coles *et al.*, 1999; Hewitt, 2002). In a recent comprehensive evaluation of global marine and estuarine invasions (Hewitt and Campbell, 2008) based on over 700 data sources, 1 781 invasive species were identified representing 27 phyla; over 55 percent of the species were arthropods, molluscs and chordates (fishes and ascidians). Using life histories and literature-based evidence, over 98 percent of the 1 781 species were linked to possible transport vectors. Where species-level information was not readily available, genus-level characteristics were used to classify morphological characteristics and habitat associations. Most species had life histories allowing transport by vessels (biofouling ~55.5 percent, ballast water ~30.8 percent, historic dry-ballast ~2.3 percent). Intentional movements (e.g. for fisheries stocking, aquaculture development, biocontrol efforts, aquarium trade, live seafood trade, scientific research) involved less than 15 percent of translocated species.

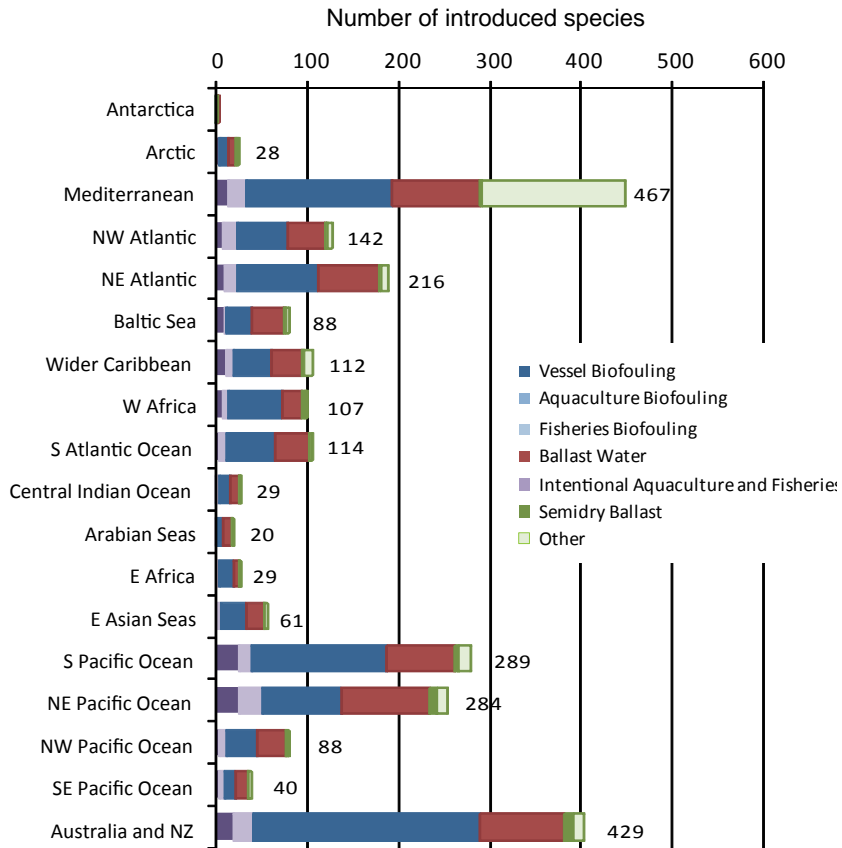
Not all bioregions of the world have experienced the same numbers or rates of biological introductions (Figure 3). An apparent acceleration of introductions, attributed to increased awareness and increasing vessel movements, has been reported in San Francisco Bay (Cohen and Carlton, 1998) and Pearl Harbor (Coles

et al., 1999), United States of America, and in Port Phillip Bay, Australia (Hewitt *et al.*, 2004) and other regions (Hewitt, 2003). Global organizations identify the need for prevention and management of transboundary marine invasions (CBD, 1992; FAO, 1995). Intentional introductions, through, for example, trade, aquaculture and live seafood, are being better controlled, and the attention is now on unintentional introductions.

The International Maritime Organization's Marine Environmental Protection Committee (IMO MEPC), adopted the International Convention on the Control and Management of Ships' Ballast Water and Sediments on 13 February 2004 (BWM, 2005). This convention aims to "prevent, minimise and ultimately eliminate the risks to the environment, human health, property and resources arising from the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments" through enforcement of guidelines and encouraging development of new ballast water treatment technologies (Gollasch *et al.*, 2007). Such current technologies include elimination through filtration and hydrostatic pressure, temperature, ozonation, ultra-violet (UV) light exposure and the use of chemicals. The majority of global invaders are transported as biofouling (Hewitt and Campbell 2008) comprising the living organisms associated with the external surfaces of a vessel, including protected areas (e.g. sea-chests, internal piping, anchor lockers, ballast tanks), which is highly diverse (Coutts *et al.*, 2010). Despite being one of the highest biosecurity threats to marine and estuarine environments, biofouling is not addressed internationally, although a recent IMO MEPC workplan includes guidelines for biofouling management. Management strategies rely on development of new techniques.

Qualitative risk analysis can be used when significant knowledge gaps exist (Hayes and Hewitt, 2000; Arthur *et al.*, 2009). It has been applied to marine biosecurity, including the identification of undesirable species, the evaluation of proposed intentional introductions, for import health standards (Campbell, 2008), identification of high-risk entry points (Gollasch and Leppakoski, 1999), monitoring and compliance control for transport vectors (Hayes and Hewitt, 2000) and identification of vectors (Hewitt and Campbell, 2008) (Figure 4). Risk analysis can be used for prevention, border protection and port-border response, but the quality of the analysis relies on the information available to the assessor (Carlton, 1996; Williamson, 1996; Hewitt *et al.*, 2004). Significant knowledge gaps include: (1) the absence of good baseline information in coastal zones (specifically ports and marinas); (2) knowledge of current and future trading patterns associated with transport vectors, due to new free trade associations; and (3) knowledge of the physical, ecological, environmental, economic and social (including human health) impacts. Until these gaps are filled, marine biosecurity will continue to focus on reactive, stop-gap measures, rather than the international, consistent framework established in the terrestrial environment.

FIGURE 3
Number of marine introductions (introduced and cryptogenic species) in the 18 large-scale International Union for Conservation of Nature (IUCN) marine bioregions according to contribution of specified transport mechanisms: biofouling (vessels, aquaculture species and gear, fisheries gear), ballast water, intentional introductions through aquaculture and fisheries and other. Numbers at the end of bars represent total number of introduced and cryptogenic species identified from the region

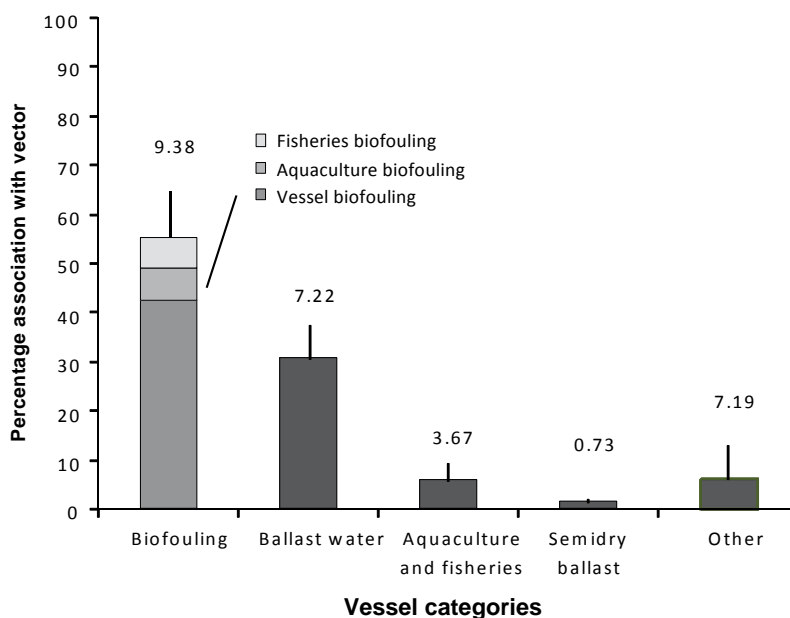


Source: Hewitt and Campbell (2008).

Climate change

Climate change is another area which was not addressed by the 2000 Bangkok Declaration and Strategy. Climate change can be the result of both natural and anthropogenic causes. Aquatic animals are very vulnerable because water is their life-support medium and their ecosystems are fragile. For example, in the case of epizootic ulcerative syndrome (EUS), temperature and rainfall are critical ecological factors for the disease. *Perkinsus olseni*, a major pathogen of molluscs, affects more than 100 host species and is temperature dependant.

FIGURE 4
Average percentage of species in each of the 18 International Union for Conservation of Nature (IUCN) bioregions with potential to be transported by major vector categories. Standard deviations of the mean for each vector are presented by error bars and numbers above the line



Source: Hewitt and Campbell (2008).

Many susceptible hosts are major food commodities. Red tides (harmful algal blooms) are influenced by climate change and spread into new locations through ballast water from ships. Climate change scenarios (e.g. sea level rise, increased incidence of storm surges and land-based run-offs, extreme weather events) that may affect biosecurity (e.g. by increasing range of pests and pathogens, intensities of their occurrence and vulnerabilities of farmed animals to diseases) will also be significant and will need to be addressed (Bondad-Reantaso *et al.*, 2005; Bondad-Reantaso and Subasinghe, 2008; Arthur *et al.*, 2009). Climate change impacts may include change in pathogen virulence and transmission, local extirpations and introductions. There is also the risk of escapes from storm-damaged facilities. The effects on parasites of climate change impacts such as alterations in host distribution, water levels, eutrophication, stratification, ice cover, acidification, oceanic currents, UV-light penetration, weather extremes and human interference also need to be understood. Climate-mediated physiological stresses such as coral bleaching and El-Niño high temperature rise may compromise host resistance and increase the occurrence of opportunistic diseases.

Expectations and commitments expressed in the Bangkok Declaration and strategy

The 2000 Bangkok Declaration and Strategy (Subasinghe *et al.*, 2001) listed the following action plans that will support the sustainable development of aquaculture:

Section 3.11 of the action plans, “Managing aquatic animal health”, includes the following:

- developing, harmonising and enforcing appropriate and effective national, regional and inter-regional policies and regulatory frameworks on introduction and movement of live aquatic animals and products to reduce the risks of introduction, establishment and spread of aquatic animal pathogens and resulting impacts on aquatic biodiversity;
- capacity building at both institutional and farmer levels through education and extension;
- developing and implementing effective national disease reporting systems, databases, and other mechanisms for collecting and analysing aquatic animal disease information;
- improving technology through research to develop, standardise and validate accurate and sensitive diagnostic methods, safe therapeutants, and effective disease control methodologies, and through studies on emerging diseases and pathogens;
- promoting a holistic systems approach to aquatic animal health management, emphasizing preventative measures and maintaining a healthy culture environment; and
- developing alternate health management strategies such as the use of disease resistant, domesticated strains of aquatic animals to reduce the impact of diseases.

Section 3.13 of the action plans, “Applying genetics to aquaculture”, includes:

- developing and utilising improved domestication and broodstock management practices and efficient breeding plans to improve production in aquatic animals.

Section 3.14 of the action plans, “Applying biotechnology”, includes:

- developing and applying biotechnological innovations for advances in nutrition, genetics, health and environmental management; and
- addressing the potential implications for aquaculture of biotechnology, including GMOs and other products, in a precautionary, safe and practical way.

Section 3.15 of the action plans, “Improving food quality and safety”, includes:

- promoting the application and adoption of international food safety standards, protocols and quality systems in line with international requirements such as the Codex Alimentarius; and

- adopting international protocols for residue monitoring in aquaculture and fishery products.

Implementation

During the last decade, aquatic animal health management and biosecurity governance has taken different forms at various levels, involving a wide range of stakeholders. This section takes a close look at examples of what has been achieved, in terms of policy and regulatory frameworks, particularly on introduction and movements of live aquatic animals, capacity building, aquatic animal health information, farm-level biosecurity and better management practices (BMPs). Examples of progress at the global, regional and national levels are presented.

Policy and regulatory frameworks

At the global level, FAO delivers aquatic animal health services under normative and field programmes working with Members, development partners, regional and international organizations, the private sector and the fish farming communities in addressing aquatic animal health biosecurity issues in aquaculture, working on the principle that prevention is better than cure and through targeted capacity building to prevent pathogen introductions. The range of work includes promoting responsible movement of aquatic animals through effective national strategies, national policies and regulatory frameworks and technical guidelines, within the framework of the *FAO Code of Conduct for Responsible Fisheries* (FAO, 1995), as a basis for enhancing compliance with regional and international treaties and instruments (FAO, 2007b); understanding and applying risk analysis to aquaculture that supports timely assessment of threats from new or expanding species (Bondad-Reantaso, Arthur and Subasinghe, 2008; Arthur, Bondad-Reantaso and Subasinghe, 2008; Arthur *et al.*, 2009); detection and identification of the emergence and spread of diseases through surveillance programmes and diagnostic services; emergency preparedness through rapid and timely response (Subasinghe, McGladdery and Hill, 2004; Arthur *et al.*, 2005); empowering and educating farmers with information and tools such as BMPs, simple and practical biosecurity measures at the farm level, as well as organization of farmers into clusters and enhancing outreach programmes to primary producers; and promoting prudent and responsible use of veterinary medicines and vaccines as a preventative strategy (FAO, 2012b). Two of FAO's statutory bodies, i.e., the Committee on Fisheries (COFI) and the Sub-Committee on Aquaculture (SCA), provide a neutral forum for discussions on global concerns affecting aquaculture development. Past sessions of COFI (COFI 28) and SCA (COFI/SCA IV and V) have highlighted the importance of aquatic biosecurity as an essential element for sustainable aquaculture development and the need to support FAO Members to improve their capacity for "preventative actions" as well as "early action capacities" when dealing with biosecurity issues and emergencies.

Between 1999 to 2002, the FAO TCP/RAS 6714(A) and 9065(A) *Assistance for the Responsible Movement of Live Aquatic Animals* – designed to address issues concerning transboundary pathogen transfer, with a view to building capacity in the Asia region for the responsible movement of live aquatic animals – was implemented by the Network of Aquaculture Centres in Asia-Pacific (NACA) with the participation of 21 countries and territories¹. During the implementation period, 12 national, 4 regional and 4 international events (training courses, workshops and consultations) were held. Important lessons from this project include the following:

- An FAO Technical Cooperation Programme paved the way for the development of an *Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals* (FAO/NACA, 2001a,b), establishment of a regional surveillance and reporting system and an aquatic animal health information system.
- Technical support services and expert consultations helped provide a solid understanding of the general principles and the essential elements contained in the technical guidelines.
- Cooperation from member governments who participated through nominated national coordinators for aquatic animal health served as the vital link on the development of national strategies and initiation or implementation of the various provisions of the guidelines.
- Various national projects and/or donor-sponsored activities assisted, to a greater or lesser extent, in monitoring the implementation aspects of the guidelines. Such activities provided information and further guidance on which elements worked well at the ground level (and those that did not) and highlighted the gaps.
- Strong collaboration with partner organizations with similar interests helped in various ways to increase understanding and also to implement the guidelines.
- A supporting implementation strategy using the concept of “phased implementation based on national needs and priorities” provided the impetus for many years of continuous and progressive work on various aspects of aquatic animal health management.
- There was strong recognition that aquaculture development needs to focus on prevention, responsible and better health management practices and maintaining healthy aquatic production (Bondad-Reantaso, 2002; Subasinghe and Bondad-Reantaso, 2008).

FAO provided emergency technical assistance on KHV to Indonesia in 2003 and on EUS in Botswana in 2007. Both activities lead to the development of national (Indonesia) and regional (seven countries bordering the Chobe-Zambezi River) technical cooperation programmes (TCPs) to assist affected countries in

¹ Australia, Bangladesh, Cambodia, China, Hong Kong China, India, Indonesia, Iran, Japan, Korea (D.R.R.), Korea (R.O.), Lao (P.D.R.), Pakistan, the Philippines, Singapore, Sri Lanka, Thailand and Viet Nam.

understanding the disease epidemiology, establishing active surveillance and reducing the risk of further spread (Bondad-Reantaso, Sunarto and Subasinghe, 2007; FAO, 2009b).

One of FAO's core mandates is to provide technical assistance towards building capacities of member governments. Through such mechanisms as TCPs, TCP facilities, programmes funded by extra-budgetary sources, unilateral trust funds and other bilateral arrangements, human and institutional capacity development have been provided both at the national and regional levels. In the Western Balkan region (Bosnia and Herzegovina, Croatia, Macedonia, Monte Negro, Serbia), a regional aquatic animal health capacity and performance survey was conducted by FAO in 2009 (Arthur *et al.*, 2011) which became the basis for developing a regional TCP programme on improving compliance with international standards on aquatic animal health (FAO, 2011). Priority areas identified include the following: building capacity in specific areas (e.g. legislation, risk analysis, surveillance (aquatic epidemiology), diagnostics, emergency preparedness/contingency planning, aquaculture development and promotion); review of national legislation to harmonize with respect to compliance with international standards of aquatic animal health; design of a regional disease surveillance programme for aquatic animal diseases; and promoting communication mechanisms and networking systems for aquaculture development. A similar exercise was done for members of the Regional Commission for Fisheries (RECOFI) (i.e. Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates) (Arthur, Reantaso and Lovatelli, 2009) which lead to the development of a regional programme for improving aquatic animal health in RECOFI member countries (FAO, 2009). The priority areas under this programme are: governance (national policy and planning, legislation and regulation), disease diagnostics (national and regional diagnostic laboratories), aquatic biosecurity (guidelines/procedures for new aquaculture species, pathogen risk analysis, disease surveillance, regional emergency response, national and regional pathogen lists, health certification, border inspection and quarantine, disease zoning); access to information (pathogen database, aquatic animal import/export database, legislation database, expert database); and regional cooperation and networking (regional Website and regional meetings). In southern Africa, FAO's work included development of an aquatic biosecurity framework for the region (FAO, 2009a) following the incursion of an exotic fish disease, EUS, in 2006 (FAO, 2009b). The process involved several regional workshops, including a high-level scoping meeting which brought together regional fisheries and veterinary authorities. Through TCPs, FAO also provided assistance to some countries (e.g. Belize, Bosnia and Herzegovina, Latvia) in developing national strategies or policy frameworks on aquatic health or assisting in revising regulations on animal health to include aquatics. The work of FAO in the Pacific region includes promotion of responsible aquaculture development and building capacity for the application of risk analysis in aquaculture implemented through several TCPs and TCP facilities.

The World Organisation for Animal Health (OIE) promotes animal health and public health, especially in the area of international trade of animals and animal products by issuing harmonized sanitary standards for international trade and disease control, by working to improve the resources and legal framework of veterinary services and aquatic animal health services and by helping OIE Members comply with OIE standards, guidelines and recommendations consistent with the World Trade Organization's (WTO) Sanitary and Phytosanitary Agreement (SPS Agreement) (Bastiansen and Mylrea, 2010). The OIE *Aquatic Animal Health Code* and *Manual of Diagnostic Tests for Aquatic Animal Diseases* (OIE, 2011a,b) continues to be updated on a regular basis, with OIE working with OIE aquatic animal disease experts and OIE Reference Laboratories. The OIE Aquatic Animal Health Standards Commission proposes appropriate methods for surveillance, diagnosis and disease prevention and control for safe trade and international movement of aquatic animals and their products with reference to the diseases listed in the OIE aquatic code. The Commission oversees the production of the code and the manual and promotes its distribution and use by veterinary and other competent authorities (Enriquez, 2010). The World Animal Health Information System (WAHIS) was set up by OIE to fulfill one of OIE's missions to ensure the transparency of the world animal health situation. There have already been agreements signed between OIE and, for example, the Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA) and NACA as "Regional Cores" for WAHIS (Jebara, 2010). Recently OIE Delegates have been requested to designate focal points in several fields, including aquatic animal diseases. A network of focal points on aquatic animal diseases has been formed, with OIE providing the necessary learning and training opportunities in the role in the standard-setting process (Petrini, 2010). Another initiative is the performance of veterinary service (PVS). The OIE PVS Tool is designed to assist veterinary services to establish their current level of performance, to identify gaps and weaknesses in their ability to comply with OIE standards, to form a shared vision with stakeholders and to establish priorities and carry out strategic objectives.

At the regional level, in Asia, the Network of Aquaculture Centres in Asia-Pacific (NACA), an intergovernmental organization of 18 governments, works on the principles of cooperation and sharing regional resources among stakeholders (governments, institutions, individuals) and assists member governments to "*reduce the risks of aquatic animal diseases impacting the livelihoods of aquaculture farmers, national economies, trade, environment, and human health*". Table 3 shows the status of implementation of the *Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals* (FAO/NACA, 2001a,b) by the 21 participating Asia-Pacific governments over the last ten years.

Good progress has been made in disease diagnosis, aquatic animal health certification and quarantine, disease surveillance and reporting and farm-level

TABLE 3
Implementation of elements of the Asia Regional Technical Guidelines on Health Management for Responsible Movement of Live Aquatic Animals (FAO/NACA, 2001a,b) by Asian countries by 2008

Elements of the technical Guidelines	Progress made (Number of countries)		
	Good	Moderate	Low
Disease diagnosis	10	6	5
Health certification and quarantine measures	10	5	6
Disease zoning	3	3	15
Disease surveillance and reporting	8	8	5
Contingency planning	3	7	11
Import risk analysis (IRA)	4	4	13
National strategies and policy frameworks	11	4	6

health management, but progress in contingency planning, zoning and import risk analysis (IRA) has been rather limited. Three FAO/NACA regional workshops were held on the diagnosis of molluscan diseases. IRA was taught at an APEC Fisheries Working Group-funded project, “Capacity and Awareness Building on IRA for Aquatic Animals,” implemented by NACA during 2002–2004. IRA is being increasingly used by regional countries to make decisions on intentional introductions of live aquatic animals. AusAid has supported two aquatic animal health projects – (1) “Strengthening Aquatic Animal Health Capacity and Biosecurity in ASEAN” and (2) “Guidelines on Responsible Movement of Live Food Finfish in ASEAN”. These projects, implemented between 2006 and 2008, directly supported capacity building, harmonization and trade facilitation within the Association of Southeast Asian Nations (ASEAN). One of the most important achievements in the region was the formation of NACA’s Regional Advisory Group (AG) on Aquatic Animal Health, a select group of senior aquatic animal health specialists from the region tasked to provide high-level technical advice to NACA member governments. The AG meets annually to discuss important and emerging aquatic animal health issues affecting the Asia-Pacific region, as well as contributing vital disease information to relevant organizations such as the OIE and FAO. NACA has been contributing to the strengthening of regional health management and biosecurity through (i) capacity building (diagnostics, epidemiology, sampling, surveillance, risk analysis, contingency planning); (ii) development of resource material (technical guidelines, manuals, diagnostic guides, field identification guides, disease cards, extension brochures); and (iii) provision of technical assistance at the farm/local/national/regional levels. New issues such as food safety, emerging diseases and continued introductions of exotics to the region are being given special attention. NACA has embarked on a new regional initiative – identifying and establishing a three-tier regional resource base – to utilize the regional technical resources available to member countries. This includes, Regional Resource Experts, Regional Resource Centres and Regional Reference Laboratories for diseases not listed by the OIE. The capacity for disease diagnosis and that of the regional disease laboratories

has greatly increased in the last decade. There are now regional OIE reference laboratories for EUS, white tail disease in *Macrobrachium rosenbergii* and white spot disease in penaeid shrimp.

In the countries of Latin America and the Caribbean (LAC), unified development of regional aquatic animal health strategies is more recent than in Asia. Most LAC countries have general laws on sustainable fisheries and aquaculture containing articles related to aquatic biosecurity (e.g. programmes for aquatic animal health, aquatic food safety, reduction of environmental impacts), which may be supported by by-laws, technical norms and regulations. However, laws are often not applied because of lack of financial resources and weak decision-making, particularly in poorer countries. While legal frameworks and institutional arrangements permit exportation and importation of aquatic products, there is an urgent need for capacity building on risk analysis. In 2004, an Inter-American Committee of Aquatic Animal Health was created to fulfill the OIE international standards for aquatic animal health. Membership includes representatives from the private and public sectors (Martínez *et al.*, 2008). The objectives of the committee are to:

- establish direct contact with experts;
- develop strategies to fulfill OIE norms and guidelines and promote their application;
- improve harmonization of scientific and veterinary services;
- promote modifications to the OIE standards;
- improve diagnostic capacity;
- promote better surveillance systems;
- identify needs and promote capacity;
- strengthen structures and legal frameworks;
- make OIE notification procedures transparent in the region;
- harmonize technical methodologies;
- propose meetings on the objectives of the committee;
- identify experts and reference laboratories;
- facilitate bilateral adoption sanitary measures in relation to the OIE *Aquatic Animal Health Code*; and
- encourage the control of biological residues and veterinary drugs.

In 2008, the recommendations of the committee were to:

- define animal welfare for aquatic animals;
- identify an overseer of agreements, technical groups, and ensure regional capacity building;
- promote capacity building and training in aquatic animal health to professionals;
- promote aquatic animal health in veterinary schools; and
- in the next meeting, change the codes relating to crustaceans, molluscs, amphibians and ornamental fish.

In 2005, during an FAO/WHO Regional Conference on Food Safety for the Americas, 20 countries of LAC reported on their national food safety systems,

and eight recommendations included regional networks and harmonization with international regulations. Some countries based on *Codex Alimentarius* have codes of practice (COPs) and good management practices (GMPs) for food safety of aquaculture and fisheries products. They include measures to reduce risks of contamination with chemicals such as antibiotics, hormones, colorants, pesticides, heavy metals and additives, and to reduce the risk of contamination with pathogens of high risk to consumers. Chile, Colombia, Brazil, Mexico, Honduras and Cuba have also developed food safety training programmes.

About 70 percent of global biodiversity occurs in 12 countries, six of them being within the LAC (i.e. Brazil, Colombia, Costa Rica, Ecuador, Mexico and Peru). However, numerous aquatic organisms have been intentionally introduced into the LAC region for aquaculture and the ornamental fish trade. Around 30 invasive exotic species have been identified (Schüttler and Karez, 2008). Salmonids in Chile have had a negative impact, and have recently reached Patagonia, Argentina, and ornamentals in several countries have eliminated native species. The LAC countries need to identify native species for aquaculture, rather than importing exotic species.

Biotechnologies being used in the region include genetic improvement and control of reproduction, development of monosex populations, pathogen screening and disease diagnosis, vaccines, bioremediation, genetic selection to improve growth rate, and the use of probiotics, but adoption of new technologies is hampered by cost. Most countries have adapted regulations in agriculture and forestry to control the use of GMOs and LMOs in aquaculture, but application of these technologies is also expensive.

The Animal Health Strategy of the European Union (EU) for 2007–2013 is prevention is better than cure. The strategy involves prioritization of EU intervention (e.g. precautionary principle); modern animal health frameworks (e.g. OIE, *Codex Alimentarius*); animal-related threat prevention, surveillance and crisis preparedness; science, innovation and research (e.g. community and national reference laboratories).

The Secretariat of the Pacific Community (SPC) has given high priority to biosecurity issues. In 2007, the SPC organized a “Regional Workshop on Implementing the Ecosystem Approach to Coastal Fisheries and Aquaculture and Aquatic Biosecurity”. Two regional workshops on disease reporting (terrestrial and aquatic animals) were conducted in 2009 and 2010. These workshops have been supported and held in cooperation with regional and international partners such as FAO, EU, the Global Environment Fund (GEF), NACA, OIE and other regional partners.

Examples of actions at the national level include that of several countries in Latin America. Chile has active surveillance and contingency plans for high-risk

diseases of fish; Mexico has surveillance for shrimp, tilapia, trout, carp, catfish and molluscan diseases in collaboration with stakeholders; and Nicaragua has surveillance for shrimp diseases. Colombia uses IRAs to protect animal and plant health, quarantine implementation, aquatic health certification for imported live animals, and active surveillance for WSSV and food safety in shrimp culture. Ecuador had a system to detect WSSV in 2000 and 2001, and Peru had a surveillance programme for WSSV from 2001 to 2006. Chile, Mexico, Brazil, Ecuador, Colombia, Peru, Honduras, Nicaragua and others have level III diagnostic capacity for salmonids, shrimp and tilapia, sometimes cooperating with universities, research institutions and private companies. To harmonize methodologies with the OIE diagnostic manual, FAO, OIE and other organizations have initiated a regional project in the Americas to create a network of diagnostic laboratories maximizing national and regional resources. At the first meeting of the National Laboratories of the Veterinarian Services in the Americas in 2008, 15 conclusions and recommendations were made regarding the setting up of networks, evaluation of laboratories to meet OIE requirements, and the recognition of regional expertise. Molluscan diseases are not well known, and so an OIE Inter-American Technical Group on Molluscs comprised of seven experts from the Americas was formed to consider management of molluscan diseases (Cáceres-Martínez and Vázquez-Yeomans, 2008). An Inter-American Technical Group on Crustaceans and an Inter-American Technical Group on Fish were also formed but have yet to be activated.

Australia has a longer history of biosecurity than the LAC or other Asian countries. Australian Government frameworks aim to manage the risks of entry, establishment and spread of unwanted aquatic pests and diseases. The federal government controls the national borders to prevent the entry of pests and diseases, while the states/territories control postborder pest and disease risks. Coordination and integration of federal and state/territory government action is through two councils comprising federal and state/territory government ministers, and the New Zealand Government. The Australian Government established a taskforce comprising federal and state/territory and government agencies, stakeholders, research and environmental groups which recommended IRAs on live and dead aquatic animal commodities, to prevent introduction of exotic diseases, and the establishment of national emergency response plans to deal with exotic disease incursions. Consequently, the Australian Government established a joint government-industry Fish Health Management Committee charged with development of AQUAPLAN, a five-year (1998–2003) national strategic aquatic animal health management plan. AQUAPLAN 2005–2010 aimed to build on the 1998–2003 plan and focuses on specific issues to further improve Australia's aquatic animal health management. Federal aquatic disease risk management is primarily the role of the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF), which includes the Australian Quarantine and Inspection Service (AQIS). Federal and state/territory governments and other stakeholders are implementing Australia's National

System for the Prevention and Management of Marine Pest Incursions.² It has four components: (i) a national monitoring programme for early detection of new pests, (ii) building industry and community awareness and education, (iii) research and development for development of policy and management, and (iv) evaluation and review of the effectiveness of the system. Mandatory ballast water management for international shipping, introduced in 2001, accords with International Maritime Organisation (IMO) guidelines, allowing discharge of ballast in Australian waters that has been exchanged at sea by an approved method. Vessels' records of ballast exchange are audited by AQIS. In May 2005, Australia signed, subject to ratification, the International Convention on the Control and Management of Ships' Ballast Water and Sediments. There are voluntary national biofouling guidelines, developed with marine industry stakeholders for non-trading, commercial, recreational and commercial fishing vessels and the petroleum industry (Commonwealth of Australia, 2009). Importation of live aquatic species is controlled by the Environment Protection and Biodiversity Conservation Act 1999 through a List of Species Permitted Live Import. The act is administered by the federal government and border controls (AQIS). There are several hundred species of ornamental freshwater and marine fish that can be imported. Additions to the list require stakeholder consultation on IRAs, including the likelihood of establishment of self-maintaining populations and environmental impact. In 2003, Australia's fisheries managers and stakeholders initiated A Strategic Approach to the Management of Ornamental Fish in Australia. The key recommendations include a national noxious fish species list, new management frameworks for ornamentals, better communication with stakeholders and a public awareness campaign on biosecurity risks. The strengths of Australia's current biosecurity systems and the planned improvements are expected to better position Australia to meet these challenges.

Aquatic animal health networks and information

Networking on aquatic animal health through professional societies and other relevant bodies continues to be strong, a clear demonstration of the relevance of the subject and the benefits that members receive from such networks or societies. Examples of very successful and long-standing professional societies include:

- the Japanese Society for Fish Pathology (JSFP);
- the Fish Health Section of the American Fisheries Society (FHS/AFS, 40 years);
- the Fish Health Section of the Asian Fisheries Society (FHS/AFS, 24 years);
- and
- the European Association of Fish Pathology (EAFP, at least 20 years).

Aside from the OIE Aquatic Animal Health Standards Commission (OIE AAHSC), which recently celebrated its golden anniversary in 2010, there are also newly

² www.marinepests.gov.au/national_system

emerging groups, e.g. the NACA Regional Advisory Group on Aquatic Animal Health (AG, nine years) and the International Society for Aquatic Animal Epidemiology (ISAAE, at least five years).

Major veterinary conferences include aquatic animal health as one of the keynote topics, as well as changes in veterinary curricula making aquatic animal health more explicit in educational programmes.

In terms of aquatic animal health information, the sector is continuously serviced by regional and international refereed journals such as *Diseases of Aquatic Organisms*, *Journal of Aquatic Animal Health*, *Journal of Fish Diseases*, *Fish Pathology* (Japan), *EAFP Bulletin*, and the *Diseases in Asian Aquaculture* (DAA) series, as well as disease articles in other general aquaculture publications and other subject-specific journals. There are also aquatic animal health Internet-based information systems where important disease information and databases can be accessed.

OIE provides official reports of occurrence of OIE-listed diseases based on country notifications. In the Asia-Pacific, a Quarterly Aquatic Animal Disease (QAAD) reporting system, a joint FAO/NACA/OIE-Tokyo activity, has had 21 participating regional countries since 1998. The QAAD list is revised annually by the NACA AG in cooperation with OIE and FAO. The regional QAAD lists serious emerging diseases in the region (e.g. KHV, abalone viral ganglioneuritis, WTD, IMNV), some of which are OIE-listed. Information generated from these reporting systems provides an early warning of emerging diseases and information to support IRAs and manage transboundary pathogens.

Farm-level biosecurity, better management practices and good aquaculture practices

In shrimp health, with respect to wider application and improvement in biosecurity, much has been achieved by efforts that have expanded the adoption of good aquaculture practices (GAP), particularly via government extension workers and shrimp farmer associations, but there is still a need for more training and extension work.

In LAC, farm-level biosecurity strategies include codes of practice (COPs), better management practices (BMPs), technical guidelines, standards and protocols designed to promote sustainable aquaculture. These documents contain practical strategies for site selection, water quality and source of broodstock, seed, larvae and juveniles, and include food safety, quality of animal feeds, antibiotics and chemical risks during growth and harvest, as well as good husbandry practices for fish, crustaceans and molluscs. However, there are regional disparities in the implementation of COPs and BMPs. Chile has some 20 documents on GMPs; Mexico has 19 covering aquatic health, food safety, environmental protection, cleaning and disinfection; Costa Rica has seven

documents; Colombia, Brazil and Honduras have at least three documents; Uruguay has two; Peru has one manual and five bulletins related to biosecurity. Countries with fledgling aquaculture, such as many Caribbean countries, lack biosecurity guidelines or manuals. COPs and BMPs have been initiated by national or local governments, industry groups and academic institutions. COPs, GMPs and training have been implemented by salmon farmers in Chile and by shrimp farmers in Mexico, Ecuador, Colombia, Peru, Honduras and Nicaragua, but inconsistencies in application by all farmers reduces the effectiveness of these measures.

Conclusions and recommendations arising from the expert panel presentations during the Global Conference on Aquaculture 2010

Expert Panel III.3 – Improving biosecurity: a necessity for aquaculture sustainability was one of three expert themes under *Thematic Session III on Aquaculture and Environment – Maintaining environmental integrity through responsible aquaculture*. The two others were: *Promoting responsible use and conservation of aquatic biodiversity for sustainable aquaculture development* and *Addressing aquaculture-fisheries interactions through the implementation of the ecosystem approach to aquaculture*.

The expert panel presentation made the following conclusions:

- Aquaculture development (intensification, diversification and trade) brings new challenges to sustainable development of the sector; biosecurity issues are major concerns.
- Disease intelligence, research, technologies and information have greatly improved; however, there is a need to involve especially farmers/producers into the equation for effective implementation.
- There is a need to keep pace with the aquaculture landscape in terms of species, systems, technologies and environments in order to determine appropriate biosecurity measures that can be put in place at every step of the culture cycle/value chain at all levels. It must be recognized that application of biosecurity to novel species requires considerable lead-in time for information gathering (e.g. research on diseases and potential environmental impact). Biosecurity cannot be implemented in an information vacuum.
- Efforts should be focused on prevention and maintaining healthy and safe aquatic production.
- Risk analysis is an important decision-making tool and this should be supported with infrastructure, human capacity and information.

The way forward includes the following:

- National frameworks are needed to regulate, manage and control biosecurity.

- Surveillance programmes and diagnostic services are required to detect and identify the arrival and spread of pests and diseases.
- Timely assessment of the threats from new or expanding species is essential.
- Rapid response to eradicate new pests and diseases is needed before they establish and spread.
- Standardization of science-based identification of all risk pathways and high-risk organisms, and implementation of preborder, border, and postborder measures to prevent pests and diseases from entering the country are required.
- Infrastructure, human capacity, research and information to implement the above must be improved.
- Capacity building is needed at all levels.
- Regional cooperation should be enhanced to permit disease control, based on regional as well as global disease information.
- Initiatives should be undertaken to establish new aquaculture operations, such as underwater aquaculture systems to maximize utilization of the water column and seabed, or the use of the bases of marine wind turbines to anchor sea farms.

The following were also presented as the message that will be relayed to the Fifth Session of the FAO Committee on Fisheries Sub-Committee on Aquaculture:

- International and national efforts to promote biosecurity need to better reach the grassroots levels of the industry and the community stakeholders (e.g. farmers, extension services, importers, processors, boat owners, fishermen, etc.).
- Biosecurity frameworks need to keep pace with the unprecedented level of aquaculture development in terms of species, systems and technology.
- Standards on aquatic animal health for known pathogens, aquatic pests and food safety are already available, but greater commitment by governments is needed to implement these standards.
- International standards need to be developed to address the high incidence of emerging diseases of aquatic animals and aquatic pests compared to the terrestrial scenario – there is a need to complement the pathogen/pest specific approach to biosecurity with standards that deter high-risk practices.

The way forward

Biosecurity is being challenged, and will be more challenged in the foreseeable future. The growth of the world human population and the increase in human travel, along with international trade in animal and plant products will require increased vigilance at borders to stop the spread of unwanted organisms, whether as pests causing environmental damage or as agents of epizootic disease. There is a need for border agencies to recognize that potential aquatic

pathogens and pests are more likely to be introduced through ports and the ornamental fish trade than by the traditional terrestrial routes.

The review of Subasinghe, Bondad-Reantaso and McGladdery (2001) contains many elements that are still relevant. The current review provides additional insights as to how biosecurity may be addressed in a cross-sectoral and multidisciplinary manner. Effective, coordinated and proactive biosecurity systems are the product of science-based knowledge and practices used within effective regulatory frameworks backed by sufficient resources for enforcement (FAO, 2010b). As aquaculture becomes more intensive, new diseases and other problems are likely to emerge. Aquaculture biosecurity will continue to operate at three levels; a) internationally, as recognized in the Bangkok Declaration; b) regionally, as seen through various regional activities; and c) on a small scale where variables (e.g. environment, species cultured, funding, training, economics) differ within countries in a region. A crucial consideration is how to deal with “unknowns”. There is a need to forge an effective regional and international cooperation to pool resources, share expertise and information. At the global, regional or national levels, the institution mandated to ensure biosecurity would be served well by putting emergency preparedness with advanced financial planning as their core function.

Taura syndrome virus (TSV) and infectious myonecrosis virus (IMNV) are only two examples of exotic diseases that have been introduced to the Asian region through the importation of SPF *Litopenaeus stylirostris* and *L. vannamei*, respectively. Biosecurity is an important issue in the use of SPF stocks which needs to be clearly understood by importers and farmers. Once a broodstock or postlarvae produced by an SPF facility leave that facility, they are no longer considered to have SPF status for the specific pathogens indicated, since the level of biosecurity under which they are being maintained has now decreased. Because their health status is now less certain, a new historical record for that facility must be established to support any claims of health status. Every country should be wary of importing exotic crustaceans of any kind for aquaculture without going through the recommended quarantine procedures, combined with tests for unknown viruses that might be a danger to local species (Flegel, 2006c). Risk analysis is necessary to assess emerging threats from new or exotic species. These biosecurity measures should be applied even to exotic domesticated stocks that are SPF for a list of known pathogens. To reduce risks to the minimum, any country that imports exotic stocks for aquaculture should invest in establishment of local breeding centers comprised of properly vetted stocks that could be used for ongoing supply of broodstock and of postlarvae to stock cultivation ponds. This would avoid the continual risk of importing unknown pathogens that might be associated with continuous importation and direct use of exotic stocks, even from a foreign breeding center that produces SPF stocks. In shrimp health management, which are also equally important to any other aquatic animal production

system, there is still need for improvement in many areas, including the need for:

- development of domesticated and genetically improved SPF stocks for all cultivated species;
- more widespread use and standardization of diagnostic tests;
- wider application and improvement in biosecurity;
- better control over transboundary movement of living crustaceans for culture;
- investigation of the efficacy of probiotics, immunostimulants and so-called “vaccines” in full-scale field trials;
- full understanding of the host-pathogen interaction in shrimp;
- more work on shrimp epidemiology;
- more studies on molecular ecology (i.e., metagenomics) and biochemical engineering to control the microbial dynamics in shrimp ponds and hatchery tanks.

In the Latin America and Caribbean region (LAC), no national aquatic health programme to protect aquatic organisms from disease has been developed in one document. There is a need to: (a) list the pathogens present; (b) identify OIE-listed pathogens likely to be in the region; and (c) implement disease diagnosis, health certification and quarantine, disease zoning, disease surveillance and reporting, contingency plans, IRA, capacity building, national strategies and policy frameworks, education and training, and enhancement of aquatic animal emergency disease preparedness and response (FAO/NACA, 2001a,b; Commonwealth of Australia, 2005).

On disease diagnostics, validation of new diagnostic methods is essential. Nanotechnology, currently being explored for detection of food pathogens and in clinical and veterinary diagnostics, is an area which may also have useful application in aquatic animal disease diagnosis. Gene sequencing and development of pathogen microarrays and other novel methods for use in pathogen detection in aquaculture should be continuously pursued with the objectives of improving the accuracy, sensitivity, specificity and speed of tests, and their applicability for diagnosis, screening and monitoring of health status of aquatic animals in the field.

In an ideal world, farmers would have a full “tool kit” of medicines and diagnostic services to monitor, control and prevent the diseases that threaten their stock. The tool kit would comprise of vaccines for preventing the major endemic diseases, immunostimulants and other feed additives to enhance the performance of the aquatic animals under farming conditions, and a range of treatment products to cure any new or sporadic future infections. All of these products would be fully approved, documenting their quality, efficacy and safety. The farms and industry would have the support of accurate diagnostic services and the support from veterinarians or aquatic animal health professionals – allowing them to develop and implement effective veterinary health plans and

utilize the medicines in compliance with good treatment practices and industry COPs. This is already possible in some parts of the world, and the impact has resulted in great improvements in sustainability and increased productivity, as well as improved farming efficiency. However, there are still challenges in achieving this in Asia, where there are many fish and shrimp species cultured, many diverse pathogens, a diverse environment and variable access to knowledge and information. From a manufacturer's point of view, solutions to the challenges for the sustainable use of medicines in aquaculture could include international harmonization of regulatory data requirements for approving products. Some of the particular challenges relate to the claims needed to support the use of the products in the variety of species being farmed. The provision of these practical solutions needs to be backed up with effective certification and enforcement of the regulations. In conclusion, there is an opportunity to ensure the responsible and sustainable use of medicines in aquaculture world-wide. The knowledge is available and the required products are available or can be developed. With a clear harmonized regulatory environment which will ensure globally accepted standards, the needs and expectations of the producers and the consumers for safe, efficacious medicines can be met and sustainable aquaculture can be achieved. This could include:

- the idea of crop grouping, i.e. use of representative species (e.g. Atlantic salmon) of a similar group or production environment to allow use of a medication in the whole group (e.g. salmonid fish);
- extrapolation of maximum residue levels (MRLs) from major species to minor species;
- the development of a network of facilities and experts able to disseminate and validate information to support health management in a region; and
- the development and implementation of veterinary health plans so that farmers can treat and sell their produce with confidence.

Applications of transgenic fishes, the science of risk assessment, the practice of risk management, and public policies for oversight of biotechnology are all in development. Future developments will include broader appreciation within both the aquaculture and regulatory communities of both the benefits and the risks posed by production of aquatic GMOs. Recognizing that all hazards cannot be predicted nor associated risks reliably and cost-effectively quantified, there will be a broader appreciation that biosecurity is the key issue for realizing benefits while managing risks posed by production of aquatic GMOs. Hence, granting of permits for production of aquatic GMOs will be conditional upon reaching agreement on how to manage risk by means of implementing effective confinement. The granting of the first such permits is yet before us, and will be a landmark event, especially as regards the technical conditions under which production of the stock in question is permitted to go forward. The degree to which production of transgenic fish ultimately will prove sustainable will depend upon many societal decisions as to whether, and under what conditions, to utilize transgenic technology in aquaculture.

On marine invasives, filling these knowledge gaps will allow proactive marine biosecurity measures that will be consistent with the international framework established in the terrestrial environment:

- good baseline information in coastal zones (specifically ports and marinas);
- knowledge of current and future trading patterns associated with transport vectors, due to new free trade associations; and,
- knowledge of the physical, ecological, environmental, economic and social (including human health) impacts.

The application of risk analysis is at the heart of the modern approaches to biosecurity. It offers an effective management tool where by pragmatic decisions can be made that provide a balance between competing environmental and socio-economic interests, despite limited information. This tool, however, needs research, databases and other vital sources of information and knowledge so that it can effectively support biosecurity assessments, surveillance, diagnostics, early warning, and contingency planning (Arthur *et al.*, 2009).

The efforts of FAO, OIE, WHO, the EU and regional partners such as NACA (in Asia), OIRSA (in Latin America) and SPC (in the Pacific), as well as governments' individual efforts in bringing together relevant competent authorities on biosecurity governance should be continued. Effective national biosecurity governance, regional and global partnerships and champions are needed so that the risks posed by transboundary diseases of aquatic animals and other biosecurity threats can be minimized and associated losses and other negative impacts reduced. The recommendations generated from the review and the discussions and conclusions of the Global Aquaculture Conference 2010 are not directed to one single institution or stakeholder. Addressing biosecurity which transcends national boundaries should be a shared responsibility.

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Facilitating market access for producers: addressing market access requirements, evolving consumer needs, and trends in product development and distribution

Expert Panel Review 4.1

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Abstract

As one of the most highly traded food commodities, fish and fishery products form a sector that is continuing to evolve. Trends in production, trade and consumption are significantly impacting prices, product development, distribution and most notably, overall market access for producers. This paper provides a comprehensive summary of these important and emerging trends while also exploring evident consumer attitudes and purchasing behaviours around seafood. These findings represent a tremendous opportunity for the seafood sector to analyze, interpret and adapt to changes in order to remain one of the most dynamic segments in global food trade. In addition, the paper presents a useful background on the current state of the seafood sector that will enable policy-makers to make informed decisions to move fish and fishery products forward in an effective way.

Major findings on production, consumption, trade, value-chains and consumer behaviour are presented. Total world fish production continues to grow, primarily due to increases in aquaculture. Consumption of fish and fish products has risen steadily, with urbanization and the growth of modern distribution channels increasing the potential availability of fish to the world's consumers. The trade outlook remains positive, with a rising share of production from both developed and developing countries entering international markets. China is by far the largest fish exporter, but imports are rapidly growing. Other major importers include the United States of America, Japan and the European Union. With the fisheries value chain becoming increasingly globalized, production and processing are increasingly being outsourced, mostly to Asia.

Switching perspectives from producers to consumers, some general attitudes emerge. Consumers increasingly express concerns about sustainability issues, especially overfishing. Research into consumer attitudes and behaviour confirms this, and it is predicted that sustainability will continue to gain importance. The opportunity exists for the seafood industry to build on sustainability standards, allowing consumers to understand them more clearly.

Based on this in-depth analysis of the seafood sector, some key recommendations are presented as to how the sector can continue to promote growth as well as how governments can be more effective in their support. Their wider implications include facilitating market access for producers and satisfying evolving consumer needs.

KEY WORDS: *Aquaculture, Consumer needs, Market access requirements, Product trends.*

Introduction

The market for fish and fisheries products is a globalized market with almost 40 percent of total production entering international trade. Not only is this share higher than for other food or agricultural products, but the role of developing country exporters in total exports is also higher, with a share of around 50 percent. This underscores the sector's importance in contributing to local, regional and international food security in general and as a generator of economic activity, employment and of net export revenue to the developing world in particular.

International trade in fish and fishery products has grown strongly over the last decades. Despite the contraction in consumer spending after the crisis in 2008, the long-term trend for fish trade remains positive, with a rising share of both developed and developing-country production entering international markets. The potential for increased demand offers significant opportunities to aquaculture producers but also challenges their ability to find innovative ways to supply markets with products aimed at satisfying consumer needs. Potential methods could include new technology to provide more targeted portion sizes and taste varieties, as well as innovative packaging and communication strategies.

With fish production dominated by developing countries, it is no surprise that fish imports are mostly by developed countries, currently responsible for 77 percent of the total import value. This dominance presents a challenge to exporters from developing countries adhering to market access requirements as a prerequisite for entering international markets. In addition, the changing nature of these market access requirements, including the emergence of private and voluntary standards and requests for certification and labels for various purposes, puts additional pressure on producers, processors and exporters without necessarily offering higher prices to offset the additional costs incurred.

Growth of aquaculture

Total world fish production (capture and aquaculture), continues to grow. Estimates for 2010 show a slight increase from the previous year to 147 million tonnes. China¹ confirms its role as the principal producer, reporting 48 million tonnes in 2008, of which 33 million tonnes derive from aquaculture². Overall, 80 percent of world production of fish and fishery products takes place in developing countries.

¹ Excluding Hong Kong SAR and Taiwan POC, which produced 0.2 and 1.3 million tonnes, respectively.

² In 2008, China revised its 2006 production statistics by about 13 percent based on its Second National Agriculture Census conducted in 2007. This implied the downward adjustment of global statistics by about 2 percent in capture production and 8 percent in aquaculture production. Historical statistics of China for the period 1997–2006 were subsequently revised by the Food and Agriculture Organization of the United Nations (FAO), with the revision process known and acknowledged by the Chinese authorities.

Total world fish production grew to 145 million tonnes in 2009, of which 55 million tonnes came from aquaculture. For 2009, the contribution of aquaculture to the supply of fish and fishery products for human consumption (excluding fishmeal) is estimated to have reached 47 percent of the total. The rise of aquaculture in production and trade is having a significant impact on prices, product development, distribution and consumption patterns. The exact share of aquaculture in trade, however, remains unknown, given that international statistics do not distinguish between the two origins.

Compared with production figures a decade ago, the current supply represents an increase of more than 20 million tonnes. This additional supply is entirely due to increases in aquaculture production. As seen in Table 1, preliminary data for 2010 indicate that 57 million tonnes (excluding aquatic plants) or 39 percent of total output is from aquaculture. The decline in the long-term growth rate of aquaculture production is, however, cause for great concern, not only in terms of future food security, but also from a technological and managerial perspective. Nonetheless, as the volume of aquaculture product expands it might be anticipated that growth rates would lessen. It is clear that in many countries, significant challenges remain in order for the aquaculture sector to reach its full potential and become economically, environmentally and socially sustainable.

Capture fisheries production has stabilized at around 90 million tonnes with some annual variation. Estimates for 2010 confirm aggregate supplies from capture fisheries of about 90 million tonnes. This is in line with the pattern seen over the last 15 years, with total annual catches oscillating within a band of 85 and 95 million tonnes, in particular as a result of the El Niño in South America.

Large variance in consumption

World per capita consumption of fish and fishery products has risen steadily over the past decades from an average of 11.5 kg during the 1970s, to 12.5 kg in the 1980s and to 14.4 kg in the 1990s. Consumption in the 21st century has continued to grow, reaching 16.4 kg per capita in 2005 according to the most recent year for FAO food balance sheets. Preliminary figures for 2007 and 2008 show a new increase to 17.1 kg per capita. Estimates for 2009 show a slight increase to 17.2 kg per capita consumption, with the contribution of aquaculture to the food fish supply estimated at 47 percent of the total.

A large share of the rise in fish production in the world relates to China, where domestic consumption of fish and fishery products per capita has risen from less than 5 kg in the 1970s to the present 25.8 kg. In the world as a whole, excluding China's domestic consumption, average consumption per capita was 13.5 kg in the 1970s, rising to 14.1 kg in the 1980s, then falling to 13.4 kg in the 1990s. The average for the 2001–2005 period was a new increase to 14.0 kg per capita, which is still lower than the maximum levels registered in the

TABLE 1
World fish market at a glance

	2008	2009 estimate	2010 forecast	Change 2010 over 2009
	million tonnes			%
WORLD BALANCE				
Production	142.3	145.1	147.0	1.3
Capture fisheries	89.7	90.0	89.8	-0.2
Aquaculture	52.5	55.1	57.2	3.8
Trade value (exports USD billion)	102.0	95.4	101.9	6.8
Trade volume (live weight)	55.2	54.9	55.3	0.7
Total utilization				
Food	115.1	117.8	119.5	1.5
Feed	20.2	20.1	20.1	-0.1
Other uses	7.0	7.2	7.4	2.8
SUPPLY AND DEMAND INDICATORS				
Per caput food consumption				
Food fish (kg/year)	17.1	17.2	17.3	0.3
From capture fisheries (kg/year)	9.3	9.2	9.0	-1.7
From aquaculture (kg/year)	7.8	8.1	8.3	2.6

Source: FAO, Food Outlook, Global Market Analysis, June 2010 (note that totals may not match due to rounding).

1980s. In essence, much of the increase in total production of fish in the world has not only taken place in China, but has been consumed in China. For the rest of the world, consumption per capita has been remarkably stable, oscillating around 14 kg. It must also be mentioned that on the whole, developed countries have a much higher consumption of fish than developing countries, 24.0 kg per caput for the first group, 14.4 kg the latter when including China and 10.6 kg when excluding China. However, average consumption today in the developed world is lower than in the 1980s, whereas developing-country consumption has risen in both absolute and relative numbers.

There are large regional differences in fish consumption per capita, but also within regions. As noted above, China's consumption has risen to 25.8 kg per capita in 2005. Asia excluding China consumes at present 13.9 kg per capita (positive trend in the 1990s, now declining), Europe consumes 20.7 kg (positive), and North and Central America consume 18.9 kg (positive). South America consumes 8.4 kg (declining) and Africa consumes 8.3 kg (positive trend but unstable), a below-average consumption per capita. The strong projected growth in population is likely to result in further declines in consumption in South America and Africa. Significant growth potential in aquaculture production may, however, help offset this situation.

In general, urbanization and the growth of modern distribution channels for food have increased the potential availability of fish to most of the world's consumers.

In some markets, this has indeed boosted fish consumption; in others, it has not. It is evident that economic and cultural factors strongly influence the level of fish consumption, and that availability alone is not the only factor.

Long-term growth in trade

International trade in fish and fishery products grew strongly over the previous decade, reaching a new record in 2008. The economic downturn starting in the latter half of that year led to falling consumption in most countries, with a drop in imports registered in almost all markets throughout 2009. The proportion of world fishery production traded internationally (live-weight equivalent) was an estimated 37 percent in 2009. Despite the contraction in consumer spending in 2008 and 2009, the long-term trend for fish trade remains positive, with a rising share of both developed and developing-country production entering international markets. The rebound of demand in 2010 was significant, and trade figures started approaching former levels. The outlook remains positive, with new growth in trade expected, although some markets will only recover in the medium term.

Developing countries confirm their fundamental importance as suppliers to world markets, with close to 50 percent of the value and nearly 60 percent of the quantity (live weight equivalent) of all fish exports. Imports are mostly by developed countries, now responsible for about 80 percent of the total import value of USD108 billion³ (2008). This was significant, as it was the first time imports exceeded USD100 billion. In volume (live weight equivalent), the share of developed-countries imports is significantly less, around 60 percent, reflecting the higher unit value of products imported by developed countries.

Net export revenues from fish trade earned by developing countries reached nearly USD27 billion in 2008. For many developing nations, fish trade represents a significant source of foreign currency earnings, in addition to the sector's important role in income generation, employment and food security. For low-income food-deficit countries (LIFDCs), net export revenues rose to USD12 billion in 2008. LIFDCs accounted for 20 percent of total exports in value terms, a slight decrease from the previous period.

In general, the long-term rise in aggregate trade values and volumes for all commodities (except fishmeal volumes) reflect the increasing globalization of the fisheries value chain. Production and processing is outsourced to Asia (e.g. China, Thailand and Viet Nam) and, to a lesser degree, to Central and Eastern Europe (e.g. Poland and Baltic countries), North Africa (Morocco) and Central America. Outsourcing of processing takes place both on the regional and global

³ Import figures differ from export figures because the former include freight costs, whereas exports are reported at FOB values.

levels, depending on the product form, labour costs and transportation time. In general, labour cost differences play a much larger role than transportation issues. Many species, such as salmon, tuna, catfish, Nile perch and tilapia, are increasingly traded in the processed form (fillets or loins). At the same time, the growth of international or global distribution channels through large retailers has furthered this development.

The rising share of developing countries in total fish production can also be considered a form of outsourcing of production and supply, at least for the part destined to enter international markets. The share of developed countries in total production fell from 29 percent in 1997 to 20 percent in 2007. The rising share of developing countries also reflects the significant increase in aquaculture, which through economies of scale and improved technology, has reduced costs and prices and thereby expanded the market overall. However, the fact that aquaculture in both developed and developing countries increasingly faces constraints in terms of space and water is significant and cannot be neglected.

The stagnation in aquaculture production in many developed countries can often be considered a societal choice. Space and water constraints, often caused by conflict with competing activities, not the least in coastal areas, and tightened regulations in general, make domestic production less competitive, and as a result, a growing share of domestic consumption is sourced from abroad, in particular from developing-country producers.

New and emerging markets

China is by far the largest fish exporter at USD10.2 billion (2008), but its imports are also growing, reaching USD5.2 billion (2008). The increase in China's imports is partly a result of outsourcing, as Chinese processors import raw material from all major regions, including South and North America and Europe for reprocessing and export. It also reflects China's growing domestic consumption of species not available from local sources. Its main export markets are Japan, the United States of America, the European Union (EU) and the Republic of Korea. China will continue to dominate world production in the foreseeable future and will remain the largest exporter. As an importer, China is likely to soon overtake Spain as the world's third largest importing country behind only the United States of America and Japan.

The EU is the largest single market for imported fish and fishery products. This reflects its growing domestic consumption but also its increase to 27 member countries. The 2008 imports (EU-27) reached USD45.2 billion, up 7.8 percent from 2007, and represent 42 percent of total world imports. However, these statistics also include trade among EU partners. If intra-regional trade is excluded, the EU imported USD24.6 billion of fish and fishery products from non-EU suppliers, but this still makes the EU the largest market in the world, with about 23 percent of

world imports. It is important to note that EU markets are extremely heterogeneous with markedly different conditions from country to country.

The United States of America is the largest single import market and depends on imports for about 60 percent of its food fish consumption. With a growing population and a positive long-term trend in seafood consumption, imports reached USD13.6 billion in 2007 and USD15.0 billion in 2008. Imported quantities of fish products reached 2.5 million tonnes (product weight) in 2007, but fell slightly in 2008 to 2.3 million tonnes. The largest United States import item in value is shrimp, followed by salmon, lobster, crab and tuna. Together these represented 65 percent of import values in 2008. Of note is the strong increase in tilapia imports in 2008 (volume +3 percent, value +31 percent) and of catfish species (volume +21 percent, value +18 percent).

Japan, traditionally the largest single import market for fish, was overtaken by the United States of America in 2007. The long-term trend for Japanese fish consumption is, however negative, with meat consumption overtaking fish in 2006 for the first time. Japan depends on imports for about 56 percent of its food fish consumption. The main imported commodities are shrimp, tuna, cephalopods and salmon.

In addition to the three major importing markets, a number of additional markets have become of growing importance to the world's exporters. Prominent among these emerging markets are the Federation of Russia, Ukraine, Egypt and the Middle East in general. The number of individual markets of some relevance, i.e. markets with a total import value of a minimum of USD50 million, is approaching 85. This testifies not only to the global nature of fish trade, but also to how diversified trade has become.

In Asia, Africa and South and Central America, regional trade is of importance, although in many instances it is not adequately reflected in official statistics. Improved domestic distribution systems for fish and fisheries products have contributed to increased regional trade, as has growing aquaculture production. It must also be noted that domestic markets, in particular in Asia but also in Brazil, have proven resilient during the 2008–2009 period and therefore provided welcome outlets for domestic and regional producers.

The rise in consumption and imports in emerging economies goes hand in hand with the growth in consumer purchasing power and the adoption by middle-class consumers of international food habits and purchasing practices.

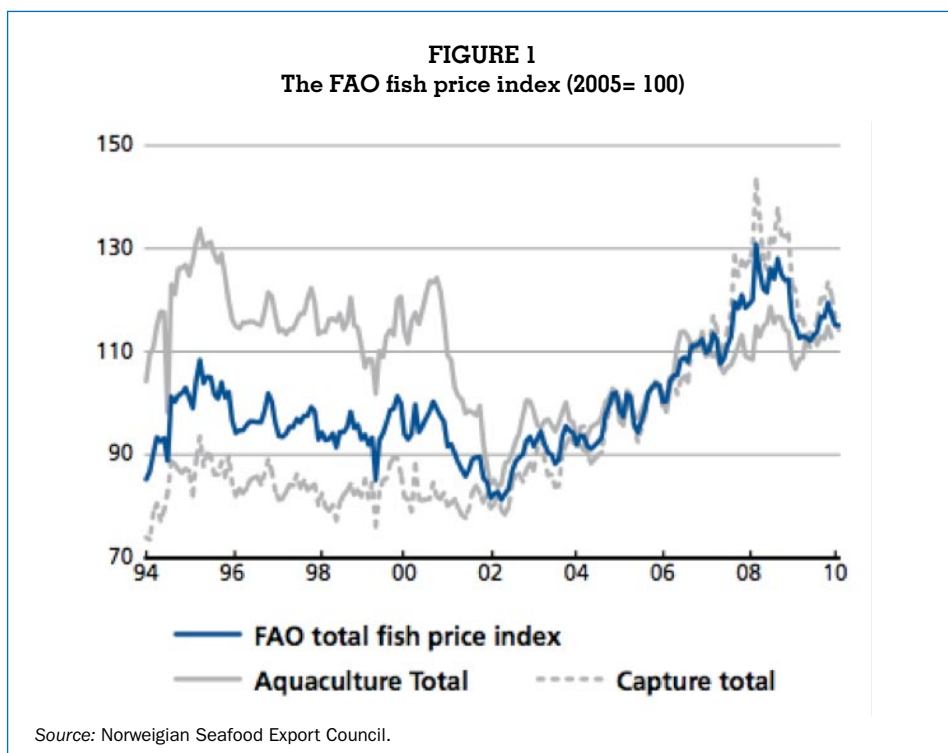
Prices

Like those of other products, fish prices are influenced by both demand and supply factors. However, the very heterogeneous nature of the sector, with

hundreds of species and many thousands of derivative products entering international trade, makes it challenging to estimate price developments based solely on supply and demand for the sector as a whole. FAO has initiated the construction of a fish price index⁴ to better illustrate both relative and absolute price movements.

As seen in Figure 1, the aggregate FAO Fish Price Index increased markedly from 81.3 in early 2002 to 126.4 in September 2008, although with strong within-year oscillation. After September 2008, the index fell drastically, reaching 110.3 in March 2009. It has since recovered dramatically to 132 in December 2010 (base year 2005 = 100). This means that current fish prices are higher than they ever have been.

In addition to the aggregate index, separate indices have been developed for the most important commodities, as well as for capture and farmed species. It is interesting to note that the index shows quite separate price developments over time for captured fisheries and for aquaculture. The former increased significantly in the period 2002–2008, whereas aquaculture prices, despite some firming during the same period, were lower in 2008 than they were ten years ago. The main reason for this is most likely related to the cost of input



⁴ The index is being developed in cooperation with the University of Stavanger and with data support from the Norwegian Seafood Export Council.

factors and the difference in production levels over this period; capture fisheries are frequently energy and capital intensive, whereas large-scale commercial aquaculture, although capital intensive, has benefited to a greater degree from technological improvements and economies of scale. This has increased yields in production, and together with improved logistics and distribution systems, permitted a significant increase in farmed output, but at lower prices.

However, because of the drop in demand during 2009 and reduced access to credit, many aquaculture producers cut back on production. As an example, farmed shrimp production registered its first decline ever in 2009. When demand picked up in 2010, the resulting shortage of supply quickly drove prices on many farmed species strongly upward. As a result, the index for aquaculture species showed an increase in value from 103 in December 2009 to 134 in December 2010.

Value-chain developments

In general, the long-term rise in aggregate trade values and volumes for all commodities reflects the increasing globalization of the fisheries value chain. Production and processing is outsourced to Asia and, to a lesser degree, Central and Eastern Europe, North Africa and Central America. This includes the rising share of aquaculture production in developing countries. Outsourcing of processing takes place both at the regional and global levels, depending on the product form, labour costs and transportation time. In general, labour cost differences play a much larger role than transportation issues. At the same time, the growth of global distribution channels through large retailers has furthered this development.

A value-chain analysis can be useful in addressing emerging issues of relevance. Fisheries value chains contain numerous stakeholders and are impacted by the factors listed below to a varying degree, depending on their position in the value chain, their contractual relationship and the relative strength of negotiation in their relationship with suppliers and clients. In addition, whereas some of these factors are of a more transitory nature with an immediate market impact, others are of a long-term nature in which the real impact may only be speculative at this stage.

Some of the major issues concerning international trade in fishery products are:

- introduction of private standards by international retailers, including for environmental, ethical and social purposes;
- continuation of trade disputes related to farmed products (i.e. catfish species, shrimp and salmon);
- the growing concern of the general public and the retail sector about overexploitation of certain fish stocks, in particular of bluefin tuna;

- widespread concern in exporting countries about the impact on legitimate exports by the 2010 introduction of new traceability requirements in major markets to prevent illegal, unreported and unregulated (IUU) fishing;
- the approval by FAO conference at its thirty-sixth session in 2009⁵ of the Agreement on Port State Measures to prevent, deter and eliminate IUU fishing;
- the proliferation of ecolabels and their uptake by major retailers;
- the increasing activity of high-profile non-governmental organizations (NGOs) in attempting to influence fish consumption and related trade patterns;
- organic aquaculture and the introduction of new standards in major markets;
- certification of aquaculture in general;
- the multilateral trade negotiations in the World Trade Organization (WTO), including the focus on fisheries subsidies;
- dissipation of economic rent in the fisheries sector due mainly to overcapacity;
- climate change, carbon emissions, food miles and the impact on the fisheries sector;
- energy prices and the impact on fisheries;
- rising commodity prices in general and the impact on producers as well as on consumers;
- the impact on the domestic fisheries sector from a surge in imports of farmed products, in particular of pangasiid catfish;
- the role of the small-scale sector in future fish production and trade;
- the availability of inexpensive communication technology and the uptake among small-scale producers to improve access to price and market information;
- notwithstanding information and communications technology (ICT) innovations, asymmetries in information flow present opportunities for value-chain actors (commonly downstream) to exercise controls;
- prices and distribution of margins and benefits throughout the fisheries value chain;
- increasing industrial concentration, notably within the retail (supermarkets) sector and to a lesser degree, foodservice, creating barriers to entry;
- the need for competitiveness versus other food products;
- economic integrity throughout the value chain; and
- perceived and real risks and benefits from fish consumption.

Of particular concern is the role of the small-scale producer, whether in capture fisheries or in aquaculture. The fragmentation of production and the vast numbers of operators at the first level of production has always weakened their commercial negotiating position. More recently, however, the fragmentation and lack of organizational structures have become a weakness in areas of quality and safety for which more formal structures are required, as these are necessary

⁵ FAO Conference at its Thirty-sixth Session on 22 November 2009, through Resolution No 12/2009, under Article XIV, paragraph 1 of the FAO Constitution.

for the implementation of new requirements such as traceability. As a response, small-scale producers in some countries, in particular in Asia, have developed producer groups or clusters. This has enabled them to share resources and enter the formal economy and the value chain on their own collaborative merit. In addition, it has facilitated transfer of know-how and experience, thereby improving production yields and economic results.

New regulations in major markets on traceability to prevent IUU fishing will, at least in the initial phase of implementation, place an additional burden upon many developing countries' fisheries, whether small-scale or not. From 1 January 2010, the EU's Regulation (EC) No. 1005/2008 requires that imports of wild-caught fish and fishery products supplied to EU member states from third countries be accompanied by a catch certificate validated by the competent fisheries management authority of the flag state of the vessel that caught the fish. Many exporting countries fear the impact on their legitimate exports, in particular where institutional weaknesses or lack of data prevent them from adequately managing their fisheries to the extent required. Although this regulation applies to products from capture fisheries, there is a general demand for improved traceability and certification for all fish and fishery products, in particular at the business-to-business level.

The fragmentation of fishery producers continues to hamper their ability to respond proactively to emerging issues and challenges advocated by consumer groups, retailers and civil society through NGOs, and to regulatory initiatives by governments. In particular, the harvesting sector has at times seemed reluctant to engage in a proactive dialogue with civil society and consumers on the legitimate role of modern fisheries and its future. A more active role in the debate involving producers, government, science and civil society would enable industry to address the issue of sustainability from an economic and social perspective, rather than being forced to respond to external pressure on environmental factors alone.

Over time, processors in developed countries have seen margins decrease, mainly due to high labour costs and strong competition from efficient producers in developing and transition countries. As a result, raw material is more frequently being sent to low-cost processing countries. In the European and North American markets, frozen products are frequently processed in Asia. Smoked and marinated products in Europe, for which shelf-life and transportation time is important, are increasingly being processed in Central and Eastern Europe. Processors have, through improved processing technology, been able to achieve higher yields and a more profitable product-mix from the raw material. Producers of traditional products, in particular of canned fish, have been losing market share to suppliers of fresh and frozen products as a result of long-term shifts in consumer preferences. Consequently, the price of canned fish products has dropped in most markets.

One widely debated issue, especially among producers, is that of the role of the retail sector within the distribution channel. It is often stated that the retail sector takes a disproportionate share of the value created from fish and fishery products. Many studies indicate that their share is indeed large, yet most of these studies do not include cost or net margin considerations, nor do they consider the intense level of competition at the retail level which normally would bring down any abnormal profit. In fact, industry reports in both Japan and the United States of America indicate that the retail chains have lower net margins on fish products than on other products. More studies are needed to look further into this relationship, including on how shorter distribution channels between the producer and the consumer can improve efficiency and increase benefits, in particular to the primary producer.

Consumers are increasingly being encouraged to express concerns about sustainability issues, especially overfishing and global warming. Much of this initiative emanates from NGOs, related media coverage and consequently chain actors eager to be perceived consistent with emergent concerns and to demonstrate their corporate social responsibility (CSR). Within the supermarkets' product range, fish has the attractive characteristic of being separable and readily identifiable, yet not being overly important in terms of turnover, to serve as an indicator of sustainable purchasing practices. Inferences to other components of their product range are seldom questioned nor substantiated. Air transportation of food is increasingly questioned, although a detailed and more objective assessment is often lacking. Health and well-being are other factors influencing consumption decisions; this explains in part the rise of the organic food sector, and related emphasis upon responsible sourcing. In the fisheries sector, organic production has been hampered by lack of market-wide standards in the most important markets, and by trenchant divisions as to whether this might be restricted to aquaculture or capture fisheries. New regulations in the EU and the United States of America have the potential to lower costs of certification and thereby increase the market for organic seafood products. Supply remains a weak point given the narrow range of species and products currently available. However, the principal purchasing parameters among consumers remain price and food safety⁶. The perceived benefit of fish consumption also remains strong in most consumers' minds.

Market access and the World Trade Organization

International fish trade is governed by the rules of the World Trade Organization (WTO). After the accession of China in 2001 and Viet Nam in 2007, all major fish-producing, importing and exporting countries have become WTO members, with the exception of the Russian Federation. The latter, a WTO observer, is in

⁶ Audun Lem, Lahsen Ababouch and Iddya Karunasagar, 2010. Salient issues for fish trade. FAO Aquaculture Newsletter, 45: 18–21.

the midst of accession negotiations, but its full accession remains pending. Countries that have joined WTO lately are Cape Verde and the Ukraine.

In addition to securing improved market access for their exports and more transparent and foreseeable trade rules, membership is a prerequisite for having access to the WTO Dispute Settlement Mechanism which increasingly has been used to solve disputes involving both wild and farmed fisheries products. In the future, as aquaculture products will increasingly dominate production and trade, we will most likely see a growing number of farmed species involved in international trade disputes, with subsequent recourse to the Dispute Settlement Mechanism. Farmed species involved so far have been Atlantic salmon (*Salmo salar*), seaweed and shrimp.

With international trade in fish and fishery products increasing rapidly, it is obvious that market access is of crucial importance to all exporters, and not only to developing-country exporters. In general, import duties in developed countries for this sector are quite low, with the exception of a few species of particular domestic importance. More important is the issue of tariff escalation in which raw material imports are given a lower import duty than processed products. For imports by developing countries, the picture is different, with tariffs often being prohibitively high. This particularly hurts regional trade and prevents many developing-country producers from accessing neighbouring markets and diversifying from their reliance on the large international markets.

With current import duties being low in the main international markets, the major issue of market access for developing-country exports is related to quality and safety requirements. Adhering to these market access requirements has therefore become a prerequisite for entering international markets. For this reason, international standards agreed upon by all stakeholders are important, as are rules set out to ensure that safety and quality measures are neither designed nor implemented in a manner that leads to the creation of unnecessary barriers to trade. In this respect, international standard-setting bodies such as Codex Alimentarius and the World Organisation for Animal Health (OIE) play a vital role, as do the rules and agreements of the WTO, in particular the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS agreement) and Agreement on Technical Barriers to Trade (TBT agreement).

Negotiations on new rules

The ongoing negotiations within the WTO, the so called Doha Development Agenda, was initiated in 2001. The two major issues of relevance to the fisheries sector are i) fisheries subsidies, discussed in the Negotiating Group on Rules, and ii) market access, discussed in the Negotiating Group on Non-Agricultural Market Access.

Whereas the negotiations on subsidies deal directly with overcapacity and overfishing in world capture fisheries, and therefore have little relevance

for aquaculture (although the WTO Agreement on Subsidies also applies to aquaculture), the market access negotiations have clear ramifications for the aquaculture sector.

On market access, although there is no consensus yet, there has been convergence on several issues, including the use of the so-called “Swiss formula” in future tariff reductions with separate coefficients for developed and developing country members. The texts also include an “anti-concentration clause”, to avoid excluding entire sectors from tariff cuts. There are also separate provisions for recently acceded members and for developing countries. The 32 least-developed country members (LDCs) would be exempt from tariff reductions in their own countries.

Fish and fishery products remain part of sectoral initiatives that would result in deeper voluntary cuts for certain non-agricultural products. Progress is linked to reaching a critical mass of countries signing on to the initiative and then subsequently, the implementation of further cuts in current rates.

Distribution, consumers and certification

The role of the retail sector within the distribution channel continues to be debated, especially its negotiating power on prices. Aquaculture products, however, have certain advantages over wild products that increase their share of supermarket sales; in the future, markets are more likely to distinguish between the two modes of production.

Consumers increasingly express concerns about sustainability issues, especially overfishing; although there is evidence to suggest that much of this originates more from retail chains eager to allay concerns over their green credentials rather than from consumers themselves. As a result, certification schemes for both wild and farmed products are gaining market share in many developed-country markets. However, the emergence of private and voluntary standards in addition to the fulfilment of mandatory regulatory requirements and requests for certification and labels for various purposes puts additional pressure on producers, processors and exporters. This increases costs, without the market being necessarily willing to offer higher prices to offset the additional costs incurred. Consumer confusion is also increasing, given the often divergent claims represented by many of the guides and indices promoting sustainable seafood.

As mentioned in the value-chain developments section above, global warming is another area of growing concern, with the air transportation of food increasingly being questioned. Health, well-being and consideration of fair payment to fish sources are additional factors influencing consumption decisions. However, principal purchasing parameters among consumers remain price and food safety.

Economic integrity

As there has been more emphasis placed on the environment and the state of natural resources, sustainability of sourcing has become an issue for the full distribution chain. Less focus, however, has been given to the integrity of commercial practices between economic operators in the value chain, or between the point of final sale and the consumer.

Most countries have some sort of regulations to prevent outright deception and to ensure correct information to consumers, in particular regarding labelling, but they are commonly under-resourced. In the fisheries sector, with the vast variety of species offered, the fact that many species are sold in the form of fillets or portions and the almost total lack of branding except for processed products, make enforcement of such rules a challenge. As a result, fraud does occur when many species are sold to customers, and the end result is incorrect names, incorrect provenance and most importantly, the incorrect shelf-life is marketed to consumers.

In addition, lack of industry-wide standards in areas such as glazing, injection, shelf life, etc. may lead consumers to choose the cheapest product without having any knowledge of the variance in product quality or of the real net weight. It is true that the Codex Alimentarius has standards for many of these issues, but unless adopted and integrated into national legislation, they remain voluntary and set only minimum and maximum values, thereby giving a lot of flexibility to operators.

One may object that the industry is unable to regulate itself in such matters. However, the fragmentation of the industry, the vast asymmetry in information and the lack of strong industry associations to discipline errant members make it difficult to implement minimum industry standards and to safeguard the sector's reputation in the eyes of consumers. As a result, consumers are frequently disappointed by inferior quality products, hurting overall consumption of fish and fishery products.

It is likely that in the future, this situation will improve for three reasons; (i) the rising share of aquaculture products in total supply and consumption will facilitate standardization and branding of product and fish name; (ii) the concentration at the retail level increases the reputational risk of the retailer, as consumers tend to rely on the retailer's image when choosing their point of purchase, thereby encouraging better practices throughout the value chain; and (iii) the growing use of voluntary certification and labelling for quality products. Such market-based initiatives, including use of geographic provenance, rely on industry-agreed norms and are certified by third-party bodies, thereby guaranteeing quality levels for the consumer.

It must be mentioned that many countries that are implementing programmes to encourage fish consumption also include activities for educating the consumer about how to judge fish quality. Such campaigns frequently include educational programmes aimed at school children. It must be hoped that the future consumer can have more confidence in the quality of the fish offered than is currently the case.

Despite such initiatives, in practice, most consumers will continue to use price as their most important purchase parameter, with food safety as the overriding prerequisite for any food purchase. However, the growing segmentation of the market with producers and retailers looking for opportunities to add value and margins, will see a large increase in voluntary market-based initiatives, not only in developed countries but also in emerging economies in Asia, South and Central America and Africa.

Research into consumer behaviour

When companies attempt to gauge consumer sentiment or measure the underlying parameters of consumer behaviour, they often turn to specialists in consumer research. Such specialized companies have access to a number of data sources including (i) electronic point of sale (EPOS) scanning data from store checkouts; (ii) household panel data from homes; and (iii) consumer research where consumers in various countries are asked about their thoughts and concerns on issues related to their purchasing activity. In addition, media consumption by different groups of consumers is measured to take account of which media channels are more effective for a specific target audience.

In this way, consumer research companies build up a picture of what is being done, where, by whom and most interestingly of all, why. In the following section, some of these findings are presented. A few are specific to the market for fish and fishery products; others are more generic and relate to the context within which fish consumption is taking place.

Demographic and economic trends

There are several large geo-demographic changes occurring that are worth remembering when we consider fish consumption and trade:

- The world's population is growing – currently there are 6.8 billion inhabitants on the planet. This number will continue to grow until 2050, when it is predicted to stabilize at about 9.2 billion. This is 1 billion fewer than predicted only five years ago.
- Much of this decline in the rate of global population increase is caused by declining fertility rates. This is due to increasing levels of wealth and,

as more women receive more education, they enter into careers of their own, marry later and have their first children at an older age. Additionally, lower infant mortality means that parents can be more confident that their offspring will survive childhood, and therefore they are less likely to have additional offspring to compensate for the previously felt risk. However, there are clearly still many improvements that can be made in lowering infant mortality.

- Average life expectancies continue to rise, but around the world we see large variations in life expectancy. Most Japanese, Europeans and North Americans can expect to live until they are nearly 80, more than ten years above the global average. At the other end of the scale, citizens in many developing countries have low life expectancies, some as low as just 32. This is a result of a combination of lower levels of wealth, and therefore reduced access to adequate healthcare and to safe and nutritious food, and the widespread presence of disease.
- While the world's wealth remains unevenly dispersed, economic growth over the last decades has seen a large number of people move out of poverty and reach the status of middle-class consumers, with purchasing patterns starting to resemble those of many developed-country consumers. However, it is too simplistic to equate wealth with consumer confidence, one of the key parameters underlying consumer behaviour. In consumer research, therefore, consumers are asked about how they judge the immediate future and their outlook on issues that impact their own economic situation and thereby their willingness to spend.

Consumer confidence

The Nielsen Company undertook global research to understand consumers' attitudes to various aspects relating to their shopping and consumption behaviour. Quarterly surveys conducted in over 50 countries ask respondents:

- Do you think job prospects in your country over the 12 months will be: excellent, good, not so good, bad, don't know?
- Do you think the state of your own personal finances will be: excellent, good, not so good, bad, don't know?
- Considering the cost of things today and your own personal finances, would you say at this moment the time to buy the things you want and need is: excellent, good, not so good, bad, don't know?
- Based on these responses, a Consumer Confidence Index has been constructed representing consumers' attitudes in over 50 countries.

Consumer concerns

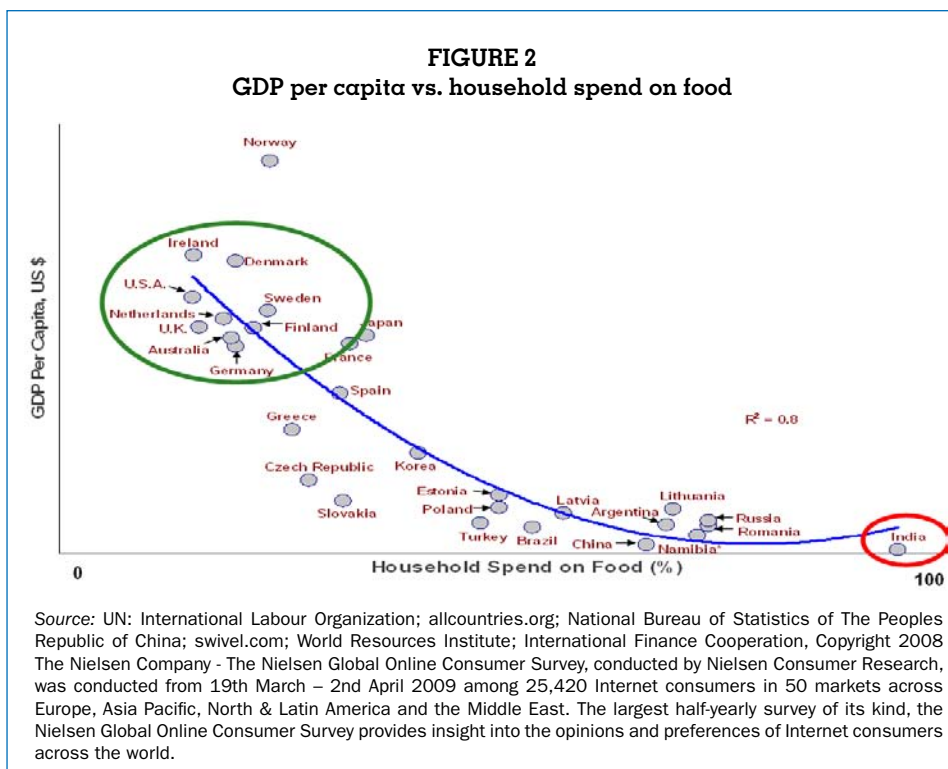
In the past decade, in most countries, health and work/life balance issues were normally in the top three concerns when asked "What is your biggest, and second biggest, concern in the next six months?" Global warming and environmental issues also started to rank among the issues consumers were

concerned about. With the economic set-back in the second half of 2008, economic issues and job security became the overriding concerns for consumers. There are however, large variations at the country level, as local issues naturally influence domestic sentiment.

In a recession, volume levels are largely static or falling, and the growth in value is mainly due to inflation, as opposed to trading up. The growth of value channels – discounters – has therefore more to do with their increased store numbers than constraints on household expenditure.

The increases observed in promotional expenditures may be because shoppers were seeking out “bargains”. This may also have been caused by an increase in the number of promotions being put in front of shoppers. In other words, if the retailer thinks that in a downturn, shoppers will want to buy more on promotion, and they are then given more promotions to buy, it becomes a self-fulfilling prophecy. This is confirmed by consumer research demonstrating that shoppers “want what they get, as opposed to getting what they want”. In this way, shopping behaviour is greatly influenced by the shopping environment and infrastructure available to them.

Despite the recession, for many consumers, especially in developed countries, consumption patterns have not changed much. This is because while consumers



do not have to buy a new car every year or have several exotic vacations, they do have to eat. Despite rising prices on a number of agricultural products and on fish, the long-term trend is towards generally cheaper food.

The household expenditure amount on food directly relates to household income. For example, a subsistence farmer in India earning less than USD1 per day would likely spend his entire income on food. In richer western countries, about 15 percent of household expenditure goes to food, which demonstrates that even after food inflation, only a small part of income is actually spent on food. Employed individuals may now have even more disposable income as they reduce their spending on big-ticket items like cars and holidays and are able to obtain historically low mortgage interest rate levels.

It is crucial for the food industry to understand that while it is not recession-proof, it is certainly recession-resistant. Sales levels are not declining; the majority of categories measured are either static or growing. As a result of growth in commoditization, there is undoubtedly pressure on categories and the value and profit they generate. This is caused by (i) the growth of discounters, (ii) increased reliance on promotional activity and (iii) the growth of private labels.

The above is also supported by aggregate trade data for 2009. International trade in fish and fishery products fell sharply in value compared with 2008. Volumes, however, were almost unchanged, declining less than 1 percent from the previous year. It was fish prices and margins that fell, not the actual quantity of fish traded and consumed. This was reinforced by consumers changing the product mix within their fish consumption, looking for value for money (i.e. farmed freshwater species rather than traditional high-value species).

Private label

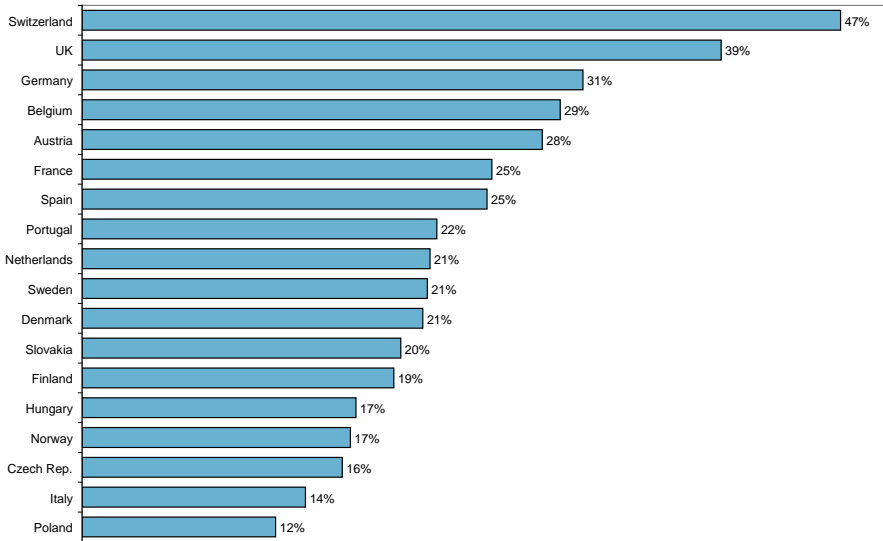
Private label's growth is only in part driven by the economic downturn, but is more a function of increasing consolidation of store ownership. Retail concentration allows chains to reach the critical mass needed to make more private label product lines viable. As their most important key performance indicator will often be the percentage profit on return achieved, decreasing brands' share is often seen as a high priority in the management of their category. The figure below shows the private label's share by country in terms of value and share.

Private labels are increasingly supported by professionally marketed initiatives. Labels evolve from being just a cheaper copy of the brand, to a more differentiated offering, with category leading innovations, at times sold at a premium to the brand.

From studies of thousands of categories in many countries over a long period of time, it becomes evident that brand owners can indeed influence the destiny of their brand and thereby mitigate the downward pressures on their categories

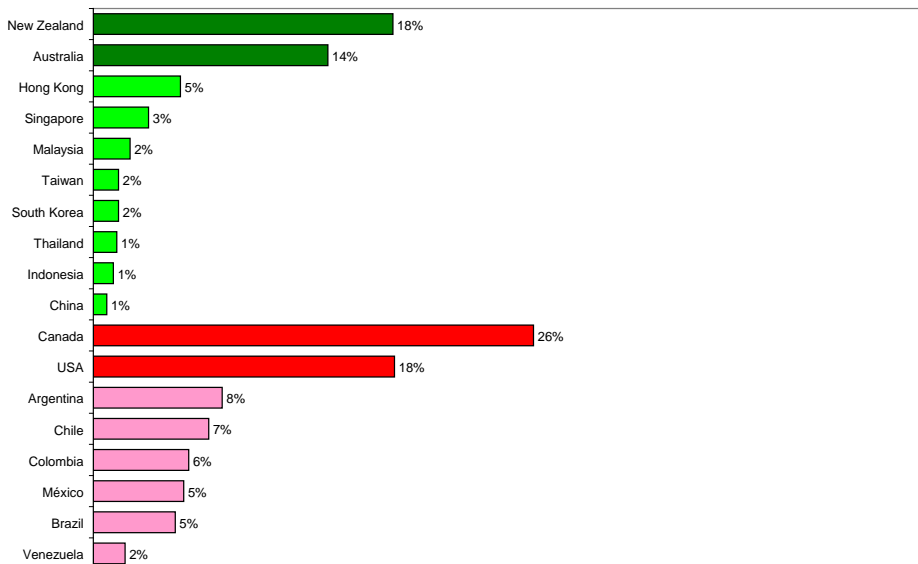
and margins. A private label does not necessarily cause brands to weaken, but if brands are already weak, private labels will take over.

FIGURE 3
Private label value (%) by country



Source: The Nielsen Global Online Consumer Survey.

FIGURE 4
Private label share (%) by country



Source: The Nielsen Global Online Consumer Survey.

Megatrends

Producers and brand owners have many options for adding value. Despite the economic downturn, consumers remain willing to spend more on products that align with these megatrends:

- health and well-being;
- indulgence and pleasure;
- convenience and practicality; and
- ethical considerations.

Going forward, the last of these megatrends – ethical considerations – is potentially the most powerful. It means different things to different people, and might include:

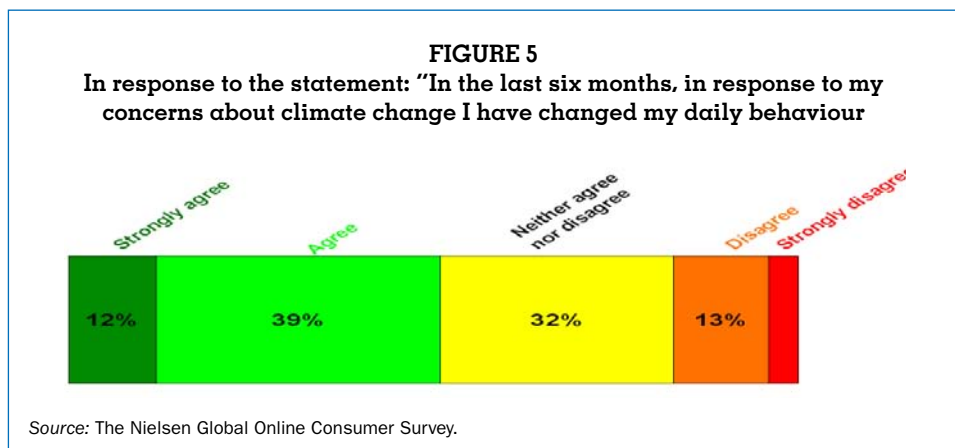
- local connection;
- animal welfare;
- sustainable sourcing (e.g. forestry or fish products; recyclable packaging);
- organic production;
- fair trade & increasing concern with intermediate labour; and
- low carbon emissions (footprint).

That sustainability is a concern is confirmed by research. The Nielsen Global Online Survey covered over 50 countries, surveying many individuals and asking a wide array of questions about consumers' attitudes and behaviours around sustainability.⁷ The figures that follow are based on these survey findings.

The majority of respondents claimed to be concerned about the global environment when asked the following question:

How strongly do you agree or disagree with the statement “I am concerned about the global environment”:

- Strongly agree: 29%
- Agree: 51%



⁷ Nielsen Global Online Survey April 2009.

TABLE 2**In response to the question: “Which of these products do you actively try to buy?”**

Type of Product	Total %
Energy efficient products or appliances	53%
Locally made products	51%
Products in recyclable packaging	45%
Products bought from a Farmer’s Market	42%
Organic Products	35%
Products with little or no packaging	31%
Fair-trade products	27%
Products that haven’t travelled long distances to get to the store	27%
Ethically produced or grown products	25%
Products that have not been tested on animals	23%

Source: The Nielsen Global Online Consumer Survey.

Do these concerns translate into action? Shoppers’ perception of ethical consumption varies greatly – here are the key findings:

Despite a probable degree of over claiming, the data indicate a propensity to want to buy what is ethically considered the superior product.

However, when trying to consume food in a more sustainable manner, there is much confusion among consumers. There has been focus on “food miles”, however a more scientific concept is carbon emissions and life-cycle analysis. This is because carbon audits often reveal counter-intuitive findings. Products transported from far away may have lower total carbon emissions than local ones – sometimes depending on the time of year or mode of transport. The carbon emissions from the energy inputs needed to grow and process a product can be much higher than those associated with transportation.

Some products declare on their packaging the carbon emissions associated with their production. However, it does not tell the consumer whether that is good, bad or indifferent. What it does demonstrate is that the manufacturer is considering food miles enough to (i) measure it, and then (ii) try to reduce it. After all, one can only effectively manage what is measured.

More fundamental questions arise about the increasing complexity of such measures and the likelihood of them being objectively evaluated by consumers. Individual food choices are made frequently (since we have to eat every day) and thus the level of involvement might be expected to be low, or certainly diminish, as repeat choices are made. It is debateable to what extent consumers will remain enthusiastic about absorbing evermore complex signals, especially when some of these may countermand earlier advice and recommendations from the same source.

TABLE 3

“Within the next 10 years, how do you think your quality of life will be affected by the impacts of climate change?”

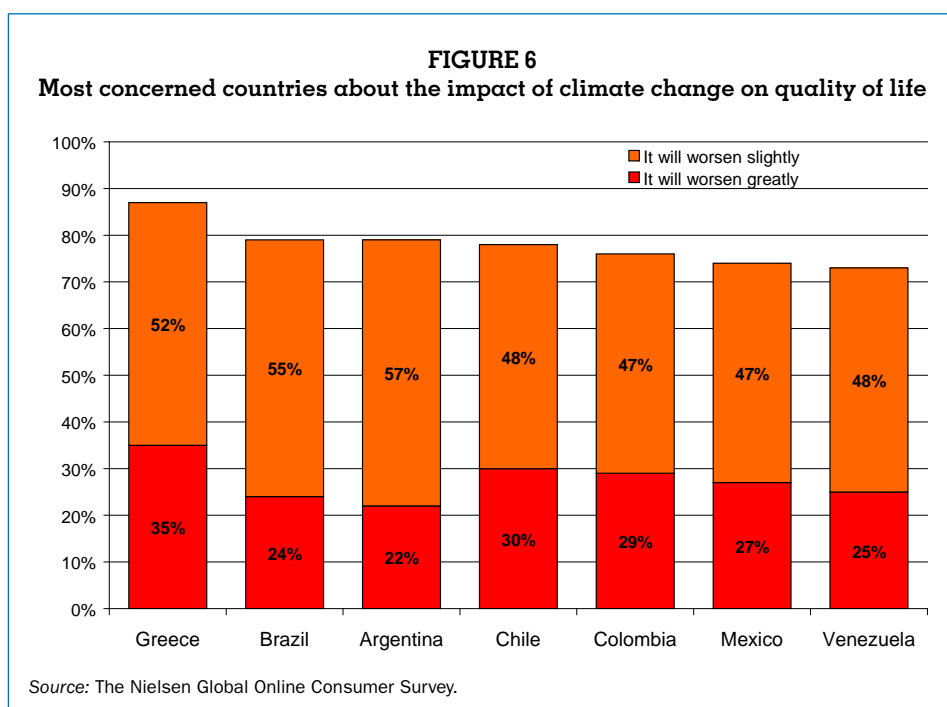
Belief	Total %
It will improve greatly	4%
It will improve slightly	15%
It will neither worsen nor improve	32%
It will worsen slightly	38%
It will worsen greatly	11%

Source: The Nielsen Global Online Consumer Survey.

The idea that certain foods are seasonal and cannot be expected to be available all year round is also gaining wider acceptance. Consumers need manufacturers and retailers, or restaurateurs, to do “choice-editing” for them and provide sustainably sourced products that are seasonally available.

Some consumers are more attuned to this than others:

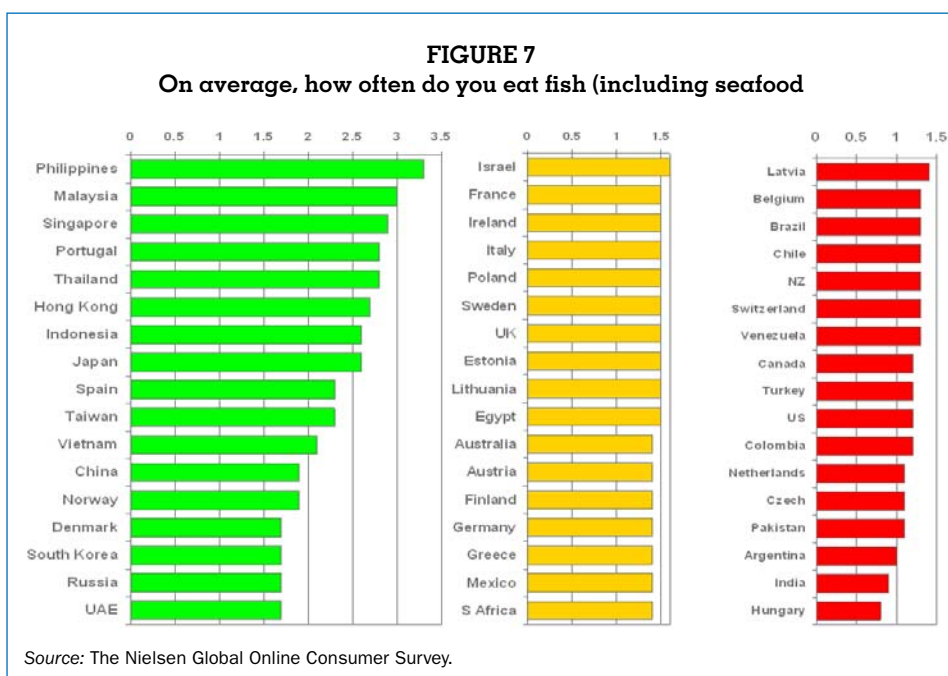
And at a country level, the most concerned countries can be seen below in Figure 8. With the exception of Greece, these countries are all in Latin America.



Fish versus meat

With the global population rising from its current 6.8 billion to a peak of 9.2 billion in 2050, a tremendous amount of additional food will be needed. There must be a sufficient quantity of food that is safe to eat and sustainably sourced for everyone.

Fish has certainly gained in popularity, and consumers are encouraged to regularly eat oily fish in order to improve the intake of long-chain omega-3 and omega-6 essential fatty acids. At the same time, consumers are encouraged to eat less red meat. Fish consumption levels vary hugely from country to country, but in the case of the Nielsen panel, 92 percent claim to have eaten fish in the last year (see figure below).



Further questions might be anticipated, as the comparatively favourable criteria for fish production are set against those for alternative protein sources, notably red meat and dairy products. For example, feed conversion ratios (FCRs) for fish compare well and with further growth only available from aquaculture, it might be logical to expect greater concern to be expressed about the relative efficiencies of utilization of fishmeal for food production. There are of course entrenched political interests within terrestrial food production sectors which may mitigate any such movements, but greater transparency as the green house gas (GHG) debates become more popularized might countermand such efforts.

Poor management of fisheries and over-fishing has led to the depletion of many species in the worlds' fisheries. Consumers are becoming more aware of the

need to ensure that the fish they buy has been sustainably sourced. Consumer awareness of the issue is currently low – but growing:

“I am concerned about overuse of global fish stocks”:

- Strongly agree: 17%
- Agree: 36%

Countries most concerned with this issue can be seen in the following figure.

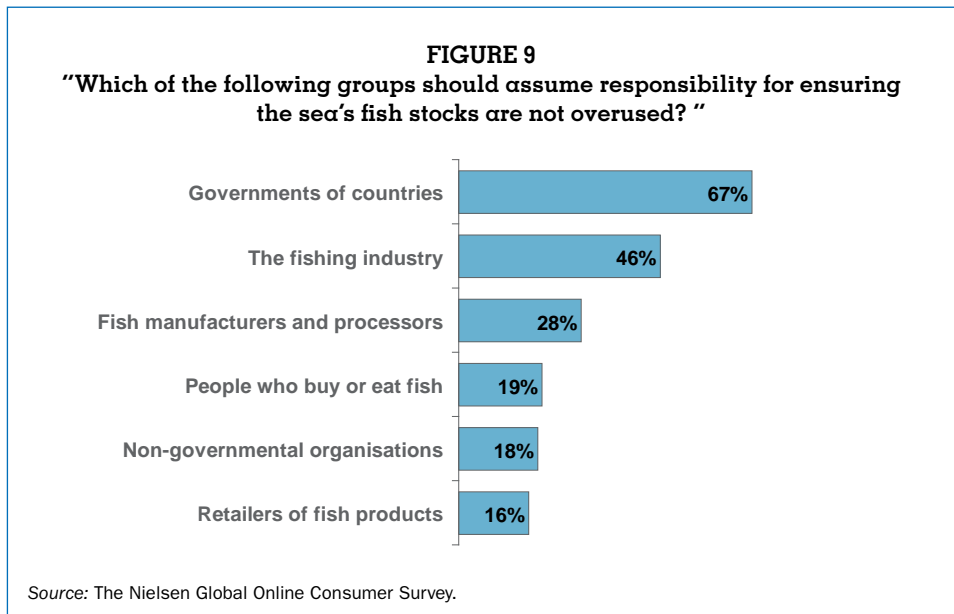
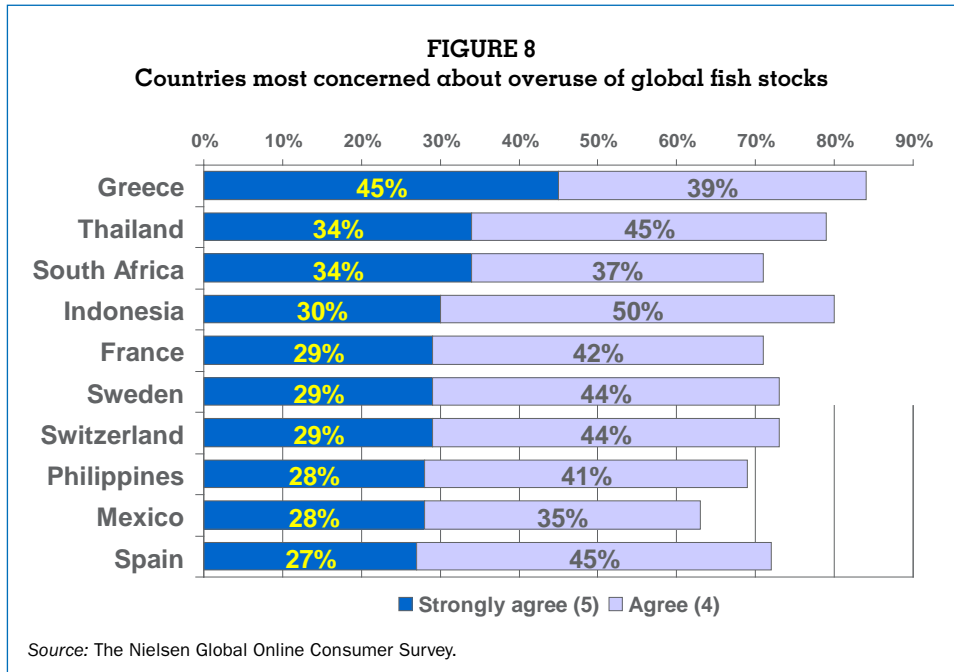


TABLE 4
“What level of influence do product labels declaring that fish is sustainably sourced have on your purchasing decision?”

Very important	27%
Important	43%
No influence on purchase decision	30%

Source: The Nielsen Global Online Consumer Survey.

But who did consumers think should take responsibility for it? Not themselves!

Over the last decade, a number of market-based initiatives have emerged in many countries to promote sustainability, with consumers having the option to buy products certified and labelled to come from sustainably managed fisheries. Starting out initially with marine capture fisheries, they now also embrace inland capture fisheries and aquaculture.

For most people, this kind of on-pack accreditation is at best a “nice-to-have” and is only a “must-have” for a minority.

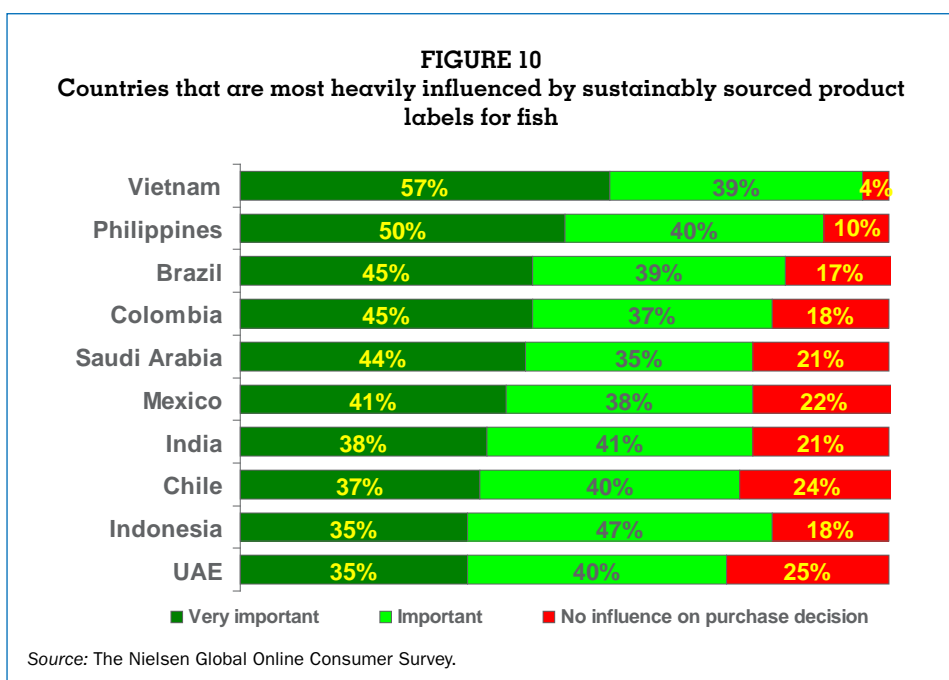
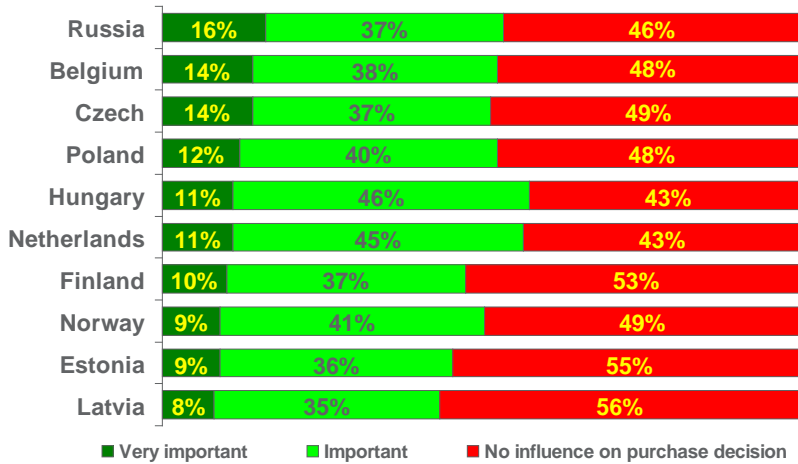


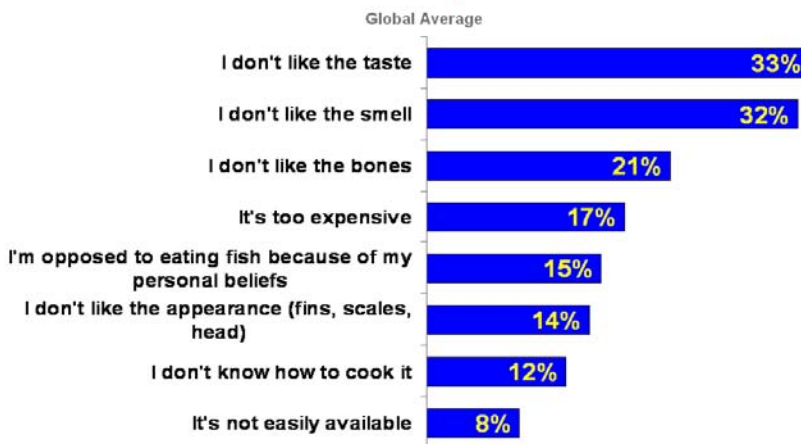
FIGURE 11
Countries that are the least engaged by sustainably sourced product labels for fish



Source: The Nielsen Global Online Consumer Survey.

However, as the following figure shows, there are other reasons why fish consumption is still low compared to many other products, including meat and poultry. It is clear that the fish industry still has significant hurdles to overcome among groups of consumers, as this research from an earlier survey demonstrated:

FIGURE 12
Global average for responses to, "What are the main reasons you don't eat fish?"



Source: The Nielsen Global Online Consumer Survey.

Outlook

Twenty years ago, when the world realized that chlorofluorocarbons (CFCs) were depleting the ozone layer, effective action was taken with the Montreal Protocol. While that was a good precedent, the world struggles with affirmative action due to the inequality that developing countries perceive from developed countries' negotiations. The follow-up to the Copenhagen Summit might help reduce emissions. Some countries with high emissions appear to be showing greater understanding of the issue and give signs of willingness to adopt policies based on science.

The food industry has much work to do in this area and needs to proceed with some urgency and above all, integrity. Marketers should not be complacent and get beguiled by trying to achieve short-term gains with “greenwash”. Similarly, when the organic industry claims their product is “better for you, and better for the planet”, they must make sure that it is. For example, carbon emissions can be lower from the non-organic alternative. Currently, there are also mixed research findings exploring organic food production's impact on nutritional value of foods and soil systems and thus, more research is needed.

We are currently in a transition phase, where displaying ethical credentials might be a differentiator in the fight for consumer loyalty. It is likely that in the future it will cease to be a differentiator – and instead become a given prerequisite for manufacturers and retailers.

In the food industry, provenance and sustainability will gain in importance. Consumers will be more discerning about why they are paying a premium for some products, and will question the value for money of more expensive products (e.g. organic food, locally sourced items or bottled water). The opportunity exists for industry to build on standards, thus making it easier for consumers to understand these issues.

In all probability, with the end to the economic downturn, we can expect a new growth in consumption. This does not mean that one will see a return to the consumer behaviour of the previous ten years. There will be changes, and not all will revert to previous patterns. The outcome is likely to be a more permanent adjustment to more prudent financial behaviour in general and more environmentally sustainable purchasing overall, both by companies and by consumers.

Around the world, as the presence of modern self-service supermarkets and hypermarkets increases, their economies of scale, especially from supply-chain savings, will be passed on to consumers, keeping a brake on inflation. Over time, with food bills becoming a smaller component of total household expenditure, in particular in emerging economies, there will be ample opportunity for the creation of new exciting, premium, value-added propositions for consumers.

Conclusions and recommendations

As issues regarding food security amplify and as the increasing affluence of developing countries leads to increased seafood consumption in these countries, the pressure on developed countries to engage a more visionary approach to aquaculture than we have seen to date will likely increase. This will further expand the opportunities for environmentally sustainable aquaculture, bearing in mind that wild catch has peaked and is unlikely to expand.

Hence in a not too distant future, aquaculture's share of total supply for human consumption will rise to somewhere between 60 and 70 percent. This will have a profound impact on the sector's ability to shape world markets in areas of pricing, product development, distribution and consumption. However, it will also challenge the sector's ability to respond successfully to evolving consumer needs. The potential for growth and economic success is evident; so are the many challenges presented to the world's aquaculture producers.

The following recommendations can be made:

1. Governments should promote integration of the small-scale aquaculture sector into the globalized market economy.
2. Governments should promote and increase the sector's competitiveness by facilitating intra-sectoral cooperation, collaboration and sharing of experience, facilitating economies of scale in purchasing, processing, certification and marketing.
3. With a growing share of seafood consumption represented by aquaculture production, the aquaculture sector will increasingly influence price formation, and product and market development in the overall fisheries sector. This will present opportunities to producers, but in order to be successful, companies will need to analyze, interpret and adapt to changes in customer and consumer needs. To this purpose, policy-makers are encouraged to promote transparency with improved data collection and dissemination throughout the value chain.

Additional reading

Recent developments in fish trade. A working document presented at the 12th Session of the FAO Committee on Fisheries Sub-Committee on Fish Trade from 26-30 April 2010 in Argentina. www.fao.org/docrep/meeting/018/k7162e.pdf

Market-based standards and certification in aquaculture

Expert Panel Review 4.2

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Abstract

Fish and seafood, including from aquaculture, are the most traded food commodity in the world. Around 32 to 40 percent of fish globally harvested entered international trade over the last 40 years, representing an export value of USD102 billion in 2008.

But to enable international market access and to ensure food safety and quality that function across national borders, credible and transparent food safety and quality systems are vital. In addition to the range of public regulatory frameworks for food safety and quality and for the protection of the environment from potential negative impacts of aquaculture, a range of related standards have been introduced by the private sector (e.g. processors, retailers) or by non-governmental organizations (NGOs). These standards and the related certification are becoming significant features of international fish trade and marketing. They relate to a range of objectives, including sustainability of fish stocks, environmental protection, food safety and quality, as well as to aspects such as animal health and welfare and socio-economic considerations. They are increasingly linked to the private firms' corporate social responsibility strategies.

This paper describes the context in which market based standards and certification in aquaculture are developing and their implication for aquaculture development and fish trade, with emphasis on the issues of relevance to developing countries.

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KEY WORDS: *Aquaculture, Market-based standards, Certification.*

Introduction

Fisheries and aquaculture are vital for global food security. For example, fisheries and aquaculture supply over 1.5 billion people with almost 20 percent of their average animal protein intake and 3 billion people with at least 15 percent of their average animal protein intake (FAO, 2010).

While fish supply from wild capture fisheries has stagnated over the years, the demand for fish and fish products continues to rise (Table 1). Consumption has more than doubled since 1973. The perceived health benefits of fish and the technological developments enabling its increased production and availability in the form of convenience products suited to modern and affluent lifestyles are key reasons for this rise in demand and consumption.

This increasing demand has been steadily met by a robust growth in aquaculture production, estimated at an average 8.3 percent yearly growth during the period 1970–2008, while the world population grew at an average of 1.6 percent per year. As a result, the average annual per capita supply of food fish from aquaculture for human consumption has increased ten fold, from 0.7 kg (8 percent) in 1970 to 7.8 kg (47 percent) in 2008, an average rate of 6.6 percent per year. This trend

TABLE 1
World fisheries and aquaculture production and utilization 2004–2009 (excluding aquatic plants)

PRODUCTION	2004	2005	2006	2007	2008	2009*
	(million tonnes)					
Inland						
Capture	8.6	9.4	9.8	10.0	10.2	10.1
Aquaculture	25.2	26.8	28.7	30.7	32.9	35.0
Total inland	33.8	36.2	38.5	40.7	43.1	45.1
Marine						
Capture	83.8	82.7	80.0	79.9	79.5	79.9
Aquaculture	16.7	17.5	18.6	19.2	19.7	20.1
Total marine	100.5	100.2	98.6	99.2	99.2	100.0
Total capture	92.4	92.1	89.7	89.9	89.7	90.0
Total aquaculture	41.9	44.3	47.4	49.9	52.5	55.1
Total world fisheries	134.3	136.4	137.1	139.8	142.2	145.1
Utilization						
Human consumption	104.4	107.3	110.7	112.7	115.1	117.8
Non-food uses	29.8	29.1	26.3	27.1	27.2	27.3
Population (billions)	6.4	6.5	6.6	6.7	6.8	6.8
Per capita food fish supply (kg)	16.2	16.5	16.8	16.9	17.1	17.2

* Data for 2009 are provisional estimates.

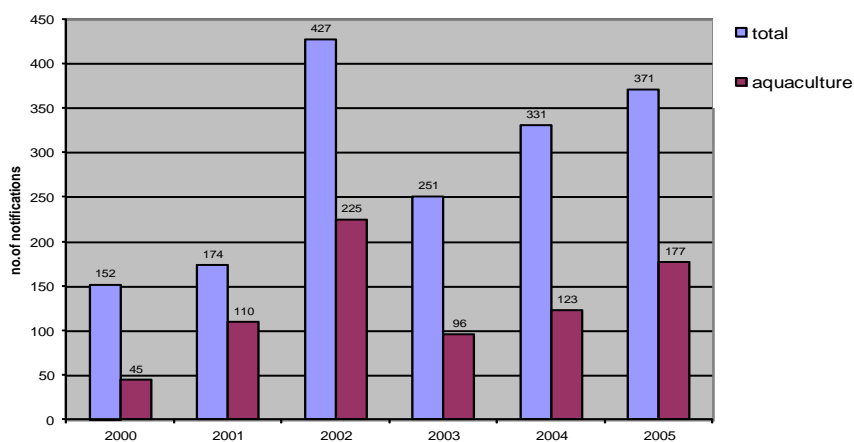
Source: FAO (2010).

is projected to continue, with the contribution of aquaculture to fish food supply estimated to reach 60 percent by 2020, if not before.

Likewise, fish and seafood are commodities that have been preserved and traded since the Bronze Age. In fact, fish and seafood are the most traded food commodity. According to FAO (2010), around 32 to 40 percent of fish globally harvested entered international trade over the last 40 years, increasing in value from a mere USD8 billion in 1976 to an estimated export value of USD102 billion in 2008. Developing countries contribute almost 50 percent in value of world fish exports, and their net receipts of foreign exchange (i.e. deducting the value of imports from the value of exports) increased from USD1.8 billion in 1976 to USD27.2 billion in 2008. This is greater than the net exports of other agricultural commodities such as rice, coffee, sugar, tea, banana and meat altogether. Three main import markets, the European Union (EU), Japan and the United States of America, acquire 70 percent of fish trade. These markets dominate international fish trade in terms of prices as well as market access requirements.

This increased globalization of fish trade has highlighted the risk of cross-border transmission of hazardous food agents, and the rapid development of aquaculture has been accompanied by the emergence of food safety and quality concerns. For example, the EU alert system for food and feed indicated that fish and fishery products have been often responsible for a large proportion, and sometimes the largest proportion (up to 25 percent), of food safety and quality alerts during the period 2000–2005. Of these, aquaculture products were involved in 28 percent to 63 percent of alert cases (Figure 1), mainly

FIGURE 1
European Union border alerts involving fish and seafood
EU Rapid Alert System-by year (2000-2005)



Source: FAO.

because of the presence of high residues of veterinary drugs, unauthorized chemicals and bacterial pathogens. For example in 2005, 177 alert cases were due to aquaculture products which contained bacterial pathogens (37 percent), nitrofurans (27 percent), malachite green (20 percent), excess residues of sulfites (13 percent) and unacceptable residues of veterinary drugs (3 percent). Similar safety problems have been reported by the control authorities of other major fish-importing countries.

Consequently, systems to enable international market access and to ensure food safety and quality that function across national borders are vital. Consumers expect that the food they purchase will be safe and of acceptable quality, regardless of how and where it is produced, processed or ultimately sold. Consumers, mainly in developed countries, are increasingly interested in the social and environmental implications of the food they consume. This trend is also starting to take hold in emerging and developing economies.

As a result, in addition to the range of public regulatory frameworks for food safety and quality and for the protection of the environment from potential negative impacts of aquaculture, a range of related standards have been introduced by the private sector (e.g. processors, retailers) or by non-governmental organizations (NGOs). These standards, referred to as private standards, and the related certification are becoming significant features of international fish trade and marketing. They relate to a range of objectives, including sustainability of fish stocks, environmental protection, food safety and quality, as well as to aspects such as animal health and welfare and socio-economic considerations. They are increasingly linked to the private firms' corporate social responsibility strategies.

This paper describes the context in which private standards and certification in aquaculture are developing and their implication for aquaculture development and fish trade, with emphasis on the issues of relevance to developing countries.

Overview of standards and certification in aquaculture

Definitions

According to ISO (2004), a standard is: *“a document established by consensus and approved by a recognized body, that provides for common and repeated use, rules, guidelines, or characteristics for activities or their results, aimed at the achievements of the optimum degree of order in a given context.”* It also notes that: *“Standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.”*

The Agreement on Technical Barriers to Trade (TBT) of the World Trade Organization (WTO, 2011b) distinguishes standards from technical regulations. A standard is “a document approved by a recognized organization or entity, that provides, for common and repeated use, rules, guidelines or characteristics for products or related processes and production methods, with which compliance is not mandatory under international trade rules. It may also include or deal exclusively with terminology, symbols, packaging, marking or labelling requirements as they apply to a product, process or production method.”

In contrast, a technical regulation is defined as: “a document which lays down product characteristics or their related processes and production methods, including the applicable administrative provisions, with which compliance is mandatory. It may also include or deal exclusively with terminology, symbols, packaging, marking or labelling requirements as they apply to a product, process or production method.”

Certification is the procedure by which a certification body or certifier gives written or equivalent assurance that a product, process or service conforms to specified requirements. Certification may be, as appropriate, based on a range of inspection activities which may include continuous inspection in the production chain (FAO, 2011). There are three main types of certification:

- *First-party certification*: by which a single company or stakeholder group develops its own standard, analyzes its own performance, and reports on its compliance, which is therefore self-declared.
- *Second-party certification*: where an industry or trade association or NGO develops standards. Compliance is verified through internal audit procedures or by engaging external certifiers to audit and report on compliance.
- *Third-party certification*: where an accredited external, independent, certification body, which is not involved in standard setting or has any other conflict of interest, analyzes the performance of involved parties, and reports on compliance.

Accreditation is the procedure by which a competent authority consistent with applicable law gives formal recognition that a qualified body or person is competent to carry out specific tasks (ISO/IEC Guide 2:2004).

An accreditation system is a system that has its own rules of procedure and management for carrying out accreditation. Accreditation of certification bodies is normally awarded following successful assessment and is followed by appropriate surveillance (ISO Guide 2, 2004).

An accreditation body is the body that conducts and administers an accreditation system and grants accreditation (ISO Guide 2, 2004).

Standards and certification schemes relevant to aquaculture products

Before describing the various standards used in aquaculture, it is useful to review what has been driving the development of standards and certification in aquaculture.

Standards, technical regulations and the certification systems sitting behind them are considered a means of assuring buyers of the safety and quality of products and the conformance of production and processing methods. Standards and certification are becoming even more important because of the increase in information asymmetry, that is, where buyers and consumers cannot easily judge certain quality aspects of products or production processes called credence goods. For example, food safety and the environmental friendliness of products are credence goods, since consumers cannot practically assess either aspect and use that assessment to inform their purchasing decisions (Washington and Ababouch, 2011). Private standards, and certification against those standards, are therefore a way of compensating for information asymmetry. Certification (and related labelling of certified products), offers verification or a “burden of proof” of compliance with the given standards.

Civil society and consumer advocacy groups are increasingly influencing the agendas of private companies, including in areas relevant to fish trade and marketing. NGOs concerned with the environmental and socio-economic aspects of aquaculture have shifted their focus to increasingly target industry players. As well as trying to influence the purchasing decisions of consumers and lobbying governments to improve their performance, over the last decade they have developed environmental standards and labelling schemes to encourage fish farmers to adopt more responsible practices.

NGOs have targeted companies' procurement policies through a variety of means, including media campaigns, organized boycotts or protests against certain retailers, or league tables announcing the most ethical supermarkets (such as Greenpeace's rankings of the sustainability of supermarkets' seafood supplies). Retailers are no longer just responding to this pressure. Indeed, it has been argued that on the basis of “enlightened self interest”, retailers and brand owners are actually driving the demand for ethical products (OECD/FAO, 2009).

Competition in the food sector is increasingly shifting from a focus on price to competition based on quality (in all its aspects) and price. In this context, retailers differentiate themselves on the basis of reputation or the overall quality image of their “brand”, including through their corporate social responsibility (CSR) policies. By adopting private standards and requiring their suppliers to be certified to a recognized international food safety management scheme (FSMS) or ecolabel, retailers can protect and even enhance their reputation and hence the value of their overall business. CSR strategies related to fish products fall

into two main areas: those relating to safety and quality (including organic, no pesticides or toxic residues, and “fresh” or “natural” type claims), and those of a broader nature related to the impacts on the wider environment (e.g. low carbon footprint, sustainable aquaculture), or to issues such as animal health, welfare or social responsibility.

From the perspective of the firm, attachment to an environmental standard provides some insurance against boycotts and bad press from environmental groups and in the media. It also helps them tap into and grow consumer demand for ethical products. Table 2 presents examples of standards and certification schemes applying to aquaculture.

TABLE 2
Standards and certification schemes operating in aquaculture

Standard (S), Code (C), guidelines (G), label (L) or certification scheme (CS)	Type	Main market orientation	Market access issues addressed				
			Food safety	Animal health	Environment	Social/ethical	Food quality
Codex alimentarius	S, C, G	Global	√	–	–	–	√
OIE*	S, C, G	Global	√	√	–	–	–
Global GAP	S, CS	Europe	√	√	√	–	√
GAA/ACC	CS, L	USA	√	–	√	√	–
Naturland	CS, L	Europe	√	–	√	√	√
Friend of the Sea	C,S	Global	–	–	√	–	–
FEAP code of conduct	C	Europe	√	√	√	√	√
ISO 22000	S	Global	√	–	√	–	√
ISO 9001/14001	S	Global	–	–	√	–	√
ASC	C, S, L	Global	–	–	√	–	–
ISEAL	S, C, L	Global	–	–	√	√	–
Scottish Salmon Producers Organization	C, L	Global	√	√	√	–	√
SIGES Salmon Chile	CS, L	Europe/USA	√	√	√	–	√
Shrimp quality guarantee ABCC, Brazil	CS, C, L	UK, Europe	√	√	√	√	√
Thai quality shrimp, GAP, Thailand	S, L	Europe/USA	√	–	–	–	√
Bio Gro, New Zealand	S, L	Global	√	√	√ Organic	–	–
Debio, Norway	CS, L	UK, Europe	√	√	√ Organic	–	–
Krav, Sweden	C, L	Europe	√	√	√ Organic	–	–
BioSuisse	C, L	Switzerland	√	√	√ Organic	–	–
NASAA, Australia	C, L	Europe	√	√	√ Organic	–	–

TABLE 2 (Continued)

Standard (S), Code (C), guidelines (G), label (L) or certification scheme (CS)	Type	Main market orientation	Market access issues addressed				
			Food safety	Animal health	Environment	Social/ethical	Food quality
Irish Quality salmon and trout	C, L	Europe	√	√	√ Organic	–	√
Label rouge, France	C, L	France, EU	√	–	–	–	√
La truite charte qualité	C, L	France, EU	√	–	–	–	√
Norway Royal Salmon	S, L	Europe	√	√	–	–	√
Qualité aquaculture de France	S, L	France/EU	–	–	√	–	√
Shrimp Seal of Quality, Bangladesh	S, L	Global	√	–	√	√	√
China GAP	C, CS	Global	√	√	–	–	√
Fishmeal and Fish Oil Organization responsible supply standard	C, CS	Global	√	–	√ Sustainability	–	√

* OIE = World Organisation for Animal Health, GAP = good aquaculture practices, GAA/ACC = Global Aquaculture Alliance/Aquaculture Certification Council, FEAP = Federation of European Aquaculture Producers, ISO = International Organization for Standardization, ASC = Aquaculture Stewardship Council, ISEAL = International Social and Environmental Accreditation and Labelling Alliance, SIGES = integrated management system for salmonids, ABCC = Associação Brasileira de Criadores de Camarão, NASAA = National Association for Sustainable Agriculture.

Source: adapted from Washington and Ababouch (2011).

Standards and technical regulations can relate to products themselves (specifications or criteria for product attributes) or to processes (e.g. outlining criteria and practices for the way products are made). Food safety standards and technical regulations typically focus on process aspects with the overall goal of improving the safety of final products. However, they can also define product specifications or criteria related to residues of additives, contaminants or microbiological criteria.

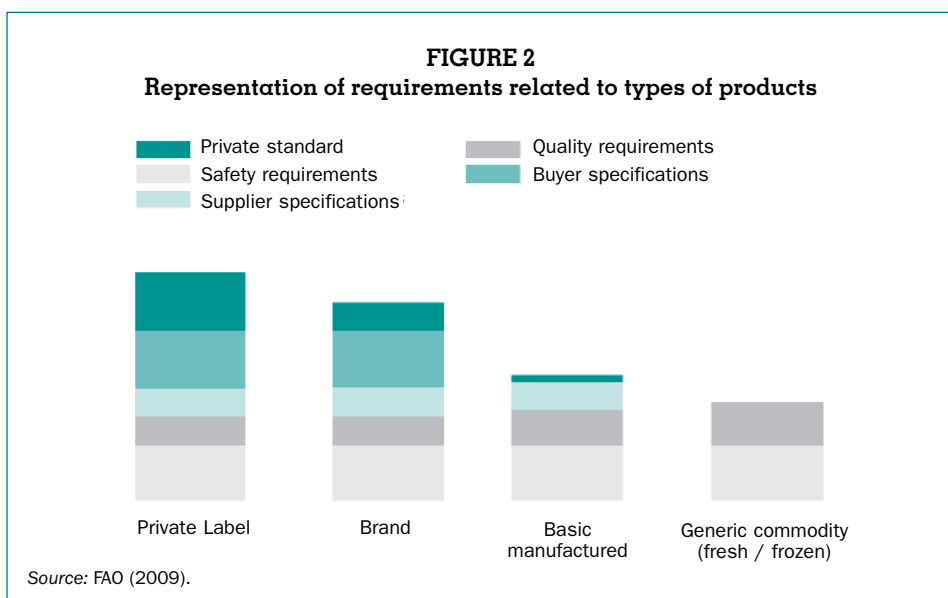
Standards, technical regulations and certification schemes are developed by:

- government institutions which enact regulations with the aim to protect consumers and/or the environment, and fair trade practices;
- buyers (retailers, processors, food service operators, etc.), whose standards are internal to the company and might simply reflect product and process specifications required of suppliers and/or requirements for certification to an independent third-party certification scheme;
- groups of producers/industry bodies, whose regulations are usually designed to promote good practices within an industry and are often referred to as codes of conduct or codes of practice;
- coalitions of retail firms, for example, the Global Food Safety Initiative (GFSI); and
- independent NGOs, such as the World Wildlife Fund (WWF).

In general, standards developed by retailers or groups of retailers primarily focus on quality and safety aspects, those developed by aquaculture producers concentrate on good practices, while those developed by NGOs are more directed at the environmental implications of aquaculture. That is not to say that retailers, for example, are not interested in environmental issues. As discussed later, the procurement policies of most large retailers and processors now include a significant sustainability-related component, but in that case they are more likely to associate themselves with an existing certification scheme than to develop their own. Standards related to food safety and quality, are typically business-to-business arrangements (B2B), whereas those related to sustainability or environmental protection, or directed to other niche markets such as organics, typically follow a business-to-consumer model (B2C). In the former case, certification is a tool for communicating assurance to buyers that the supplier is in compliance with the food safety and quality standard (although sometimes a quality mark is marketed directly to consumers). In the latter case, certification is marketed to consumers at point-of-sale, often through the medium of a label attached to the product.

The following sections present a description of some of the standards and certification schemes relevant to aquaculture. The most active and visible standards and certification schemes in aquaculture are those developed by NGOs, while others have been developed by industry organizations, separately or in collaboration with government institutions, especially in major aquaculture-producing countries.

Figure 2 shows the relative levels of compliance required depending on the type of product and level of processing. The intensity of the pressure to meet above-



the-legal-requirements, including by certification to an FSMS, varies greatly by market, by market segment (product type), and according to the importance of the segment for seafood items that carry a “name” linking products directly to a brand owner or supermarket chain.

NGO-driven standards and certification

NGOs have been active in developing private standards and related certification schemes for farmed fish and seafood. Those schemes have been borne out of a desire to improve the image of farmed fish and seafood as a safe and sustainable alternative to wild capture fish and are aimed at improving practices generally throughout the industry, including reducing the negative environmental impacts. Most of the work to improve management practices has been carried out on salmon and shrimp, mainly due to their high value and the volumes of trade they generate.

Aquaculture Certification Council

The certification scheme developed by the Global Aquaculture Alliance (GAA) is an important aquaculture scheme in terms of volumes and global coverage. GAA first developed a voluntary best practice programme for aquaculture producers, the Responsible Aquaculture Program, which included various guiding principles, codes of practice and best practice standards. Responding to industry calls for more formal recognition of these practices, GAA aligned with the Aquaculture Certification Council (ACC) (www.aquaculturecertification.org), a non-governmental body based in the United States of America, to develop a certification of aquaculture production processes. The GAA's Best Aquaculture Practices (BAP) Standards are applied in a certification system that combines site inspections and effluent sampling with sanitary controls and traceability. Certified producers are entitled to use the “BAP certification mark”, a label attached to products from certified fish farms. Standards cover a range of considerations including food safety, traceability, animal welfare, community and social welfare and environmental sustainability. Both farms and processing facilities can be certified.

As of December 2009, ACC has used independent inspectors and auditors from 30 countries to inspect aquaculture farms, conduct seminars for various governmental and non-governmental organizations in 12 countries and to audit, for certification, facilities processing aquaculture products.

The importance of the ACC scheme was enhanced by Wal-Mart's announcement that it will only buy farm-raised shrimp from ACC-certified sources. Darden's Restaurants also require its supplies of aquaculture shrimp to be ACC certified.¹

¹ Roger Bing, Vice-President Protein Procurements, Darden Restaurants, United States, in OECD/FAO (2007).

GlobalGAP

EurepGAP was developed in 1997 by the Euro-Retailer Produce Working Group (Eurep), a private-sector body driven by a group of European retailers. In late 2007, it changed its name to GlobalGAP (www.globalgap.org/cms/front_content.php?idcat=9) to reflect its more international focus. EurepGAP was initially designed as a standard for good agricultural practices. Its food safety criteria are based on hazard analysis and critical control points (HACCP).

Originally applied to fruits and vegetables, EurepGAP was later extended to fish farming practices. It was the first to develop an Integrated Aquaculture Assurance Standard (in late 2004). In addition to the general code of practice, specific criteria have also been developed for salmonids, tropical shrimp, pangasid catfish and tilapia. Its Integrated Farm Assurance Standard includes an overall base of requirements for all farms and a specific rubric of standards for crops, livestock and aquaculture.

GlobalGAP uses independent and accredited certification bodies in more than 80 countries. Notably, it also allows other schemes to be benchmarked against it. Moreover, in June 2009 it announced a “voluntary add-on module to its existing food safety, environmental and social requirements with the metrics-based environmental and social standards”² under development by the WWF Aquaculture Dialogues (described later). It is of particular interest in developing countries because it allows certification of grouped farms (rather than a separate certification for each operator). GlobalGAP has strong support in the retail sector, mainly in Europe (e.g. Royal Ahold in Holland, Carrefour in France, Tesco and Sainsbury in the United Kingdom, Aldi in Germany).

In 2009, ACC announced an agreement to cooperate with GlobalGAP (a certification scheme with strong support in Europe, discussed hereafter) to develop and harmonize certification systems for the aquaculture sector worldwide. A “joint checklist approach” to farm audit is expected to facilitate efficiencies at the farm audit level and to benefit producers exporting to both the United States of America and Europe and related seafood buyers.

World Wildlife Fund “Aqua Dialogues” and Aquaculture Stewardship Council

Following on from its involvement in the certification of sustainable forestry (Forestry Stewardship Council) and wild-capture fisheries (Marine Stewardship Council), the World Wildlife Fund (WWF) has developed standards for aquaculture certification, with the objective of reducing or eliminating the negative environmental and social impacts of aquaculture. It has organized a range of round-tables involving aquaculture producers, buyers, NGOs and other

² “World Wildlife Fund and GLOBALGAP partner on aquaculture dialogue standards” (www.globalgap.org/cms/front_content.php?idart=883).

stakeholders in an attempt to develop standards for aquaculture certification. The goal of the dialogues is to create standards for 12 aquaculture species by the end of 2011.

As with the MSC, the standard has been handed over to an arms' length independent standards-holding entity. WWF recently announced the formation of the Aquaculture Stewardship Council (ASC), which will be responsible for hiring independent third-party auditors to certify the compliance of aquaculture farms with the Aquaculture Sub-committee on Standards. Those standards concern 12 species (salmon, shrimp, pangasius, tilapia, abalone, clams, trout, oysters, scallops, mussels, seriola and cobia) considered to have the greatest impact on the environment, highest market value and/or important trading volumes in the global market. As with MSC, the ASC is also aimed at consumers, giving them “assurance that their food purchases are good for the environment”, whereas its competitors in the aquaculture area are largely B2B schemes. ASC is expected to be operational within the next two years.

Friend of the Sea

Friend of the Sea (FoS) (www.friendofthesea.org) was set up in 2006 and has origins in the Earth Island Institute. It covers both wild capture and farmed fish and seafood with an environmental focus. Its “Criteria for Sustainable Aquaculture” require, *inter alia*, that:

- an environmental impact assessment (EIA) or equivalent be run before the development of a farm;
- the farm not impact critical habitats, such as mangroves, wetlands, etc;
- procedures be in place to limit escapes of fish to a negligible level;
- genetically modified organisms (GMOs) and growth hormones not be used;
- antifouling paints not be used;
- waste, water, feed and energy management be in place; and
- only FriendOfTheSea certified feed be used (where available).³

FoS Criteria for sustainable fisheries and aquaculture also include recommendations on carbon footprint reduction and offset (20 percent per annum) and “social accountability”. However, it does not include criteria for food safety and quality.

Organic aquaculture

Other niche markets, such as organic aquaculture, are also being developed. Sometimes, certification for fish and seafood products is linked to existing certification schemes for agricultural products. For example, the United Kingdom Soil Association and the New Zealand organics certifier BioGro have added aquaculture to their schemes. There are 20–25 certifying bodies for organic aquaculture products. For example, Naturland (www.naturland.de), based in

³ Certified FoS feed ranges for seabream, seabass and trout became available in late 2009.

Germany but operating internationally, certifies organic farmed seafood. It is said to be widely accepted in both the United States of America and in Europe, although some European buyers also insist on certification by local organic organizations (such as Bio Suisse in Switzerland and the Soil Association in the United Kingdom). However, organic aquaculture accounts for very small volumes of production: only about one percent of overall aquaculture production.

Standards developed by producers and/or government institutions

As a response to the pressure by buyers for certification of aquaculture products, many industry organizations have embarked on the development of their own standards and certification schemes, including a label to be used for B2C labelling. Some of these standards are developed by government institutions, others by industry associations or through a collaboration of both. These standards have received different rates of recognition by stakeholders, especially buyers. Some standard promotion initiatives have been aborted while others are subject to continuous changes and development to adapt to market requirements and competition. The following are examples that should be considered illustrative only, and not representing the current situation.

Integrated Management System (SIGES) – Salmon Chile

The SIGES standard was developed for the Chilean salmon producers association, Salmon Chile (www.salmonchile.cl/frontend/index.asplt) is managed by the Salmon Technological Institute (INTESAL), the institute for salmon technology in Chile, and functions as a certifiable integrated management system, dealing with food safety and quality management, environmental issues, fish health and occupational safety.

It incorporates all relevant legislation, plus technical standards and is based on international norms and standards including ISO 9001 and ISO 14001.⁴ As of August 2008, 31 companies were participating in SIGES, which accounts for 90 percent of the companies associated with Salmon Chile. Wal-Mart requires that all its Chilean suppliers have SIGES certification.

The Scottish Salmon Producers' Organization

The Scottish Salmon Producers' Organization (SSPO) (www.scottishsalmon.co.uk) is the trade association for the Scottish salmon farming industry, whose membership accounts for 95 percent of the tonnage of Scottish salmon production. It has developed a Code of Good Practice for Scottish Finfish Aquaculture that includes some 300 main compliance points covering consumer assurance issues (traceability), animal health, environmental issues and feed requirements (including the sustainability of sources of fish used as fish feed). The organization also offers access to certification schemes, including Tartan Quality Mark (involving independent inspection of production processes and

⁴ ISO 14001 deals with environmental management systems (see: www.iso.org).

robust traceability requirements) and Label Rouge. Scottish salmon was the first non-French product to gain the French public quality mark described hereafter.

Label Rouge

Label Rouge is a quality label set up by the French Ministry of Agriculture in 1960 with the aim to differentiate high-quality food products from standard products of the same type. It covers various food products, especially of animal origin.

Since its launch, this label has gained widespread adoption, recognized by 80 percent of French consumers. For fish and seafood, the label covers both capture fisheries and aquaculture. It defines specific requirements for practices during production and handling and specific product criteria (e.g. color of salmon fillets) (Loreal and Falconnet, 2003).

The administration of the label is carried out by the Commission nationale des labels et certifications (CNLC). Aquaculture species that have been the subject of Label Rouge labeling are salmon from France, Scotland, Norway and Ireland, as well as seabass, shrimp, scallops and oysters from various European countries.

Thai Shrimp GAP

To maintain and expand market shares and offer its industry support services, Thailand has been trying to build its national reputation as a producer of safe, quality products. Ninety-five percent of Thai shrimp is destined for export markets. According to the World Bank (2005), Thailand has increased the proportion of value-added prepared and processed shrimp from 25 percent to 50 percent during the period 1995–2005.

The strategy pursued by the Government of Thailand has included the development of a sustainable shrimp aquaculture standard, a one-stop-shop service agency for food safety, the creation of a national committee on food safety, the alignment of national sanitary standards with international standards, and a strengthened approach to food safety management generally.

The Department of Fisheries (DoF) is actively encouraging Thailand's shrimp farmers to meet good aquaculture practice standards (Thai Shrimp GAP) or better for marine shrimp farming, incorporating various international standards including Codex, ISO 14001 and relevant FAO codes and guidelines. Processing plants must meet the requirements for HACCP certification.

It has been argued that these improvements have allowed shrimp farmers to enter into direct supply contracts with supermarkets: "Shrimp farmers now have more experience in making contracts with foreign foodservice providers themselves without using any brokers" (FAO, 2009). Moreover, to help promote exports, the Thai DoF has entered into mutual recognition agreements with

buying countries – for example, with the Republic of Korea – to speed product inspection procedures. The DoF is also one of the third-party certification bodies chosen as part of the United States Food and Drug Administration’s (US FDA) pilot programme for farmed shrimp.

United States Food and Drug Administration certification pilot program

In 2008, the US FDA initiated a voluntary third-party certification pilot programme for imported farmed shrimp. The programme responds to the “President’s Action Plan for Import Safety”, which called for the development of voluntary third-party certification programmes for foreign producers who export to the United States of America. The FDA’s Food Protection Plan (November 2008) “emphasizes qualified and legitimate third party certification as a way to help verify the safety of products from both foreign and domestic food companies.” The FDA defines a third-party certifier as any entity, private, NGO, government or stata with no conflict of interest with the FDA.

A range of certification bodies, including private certifiers like the ACC, as well as public bodies such as the Thai DoF and the United States of America Seafood Inspection Service of the National Marine Fisheries Service are part of the pilot. The intention is to evaluate third-party certification schemes with the possibility of eventually allowing products from facilities certified by those bodies expedited entry into the United States of America. This programme might signal the increasing importance of standards and certification schemes as facilitators of entry to important fish and seafood markets.

While expedited and facilitated entry has been at the center of the European Commission (EC) strategy for accreditation of “competent authorities” of exporting countries, it has involved only national food control services and mutual recognition agreements. The FDA voluntary third-party certification programme offers equal opportunities to both private and government certification systems to demonstrate their worthiness. This unique initiative may help reduce duplication between private and government certification systems. Its results and future developments should be closely monitored.

Private standards developed by importers and retailers

Setting product and process specifications, and requiring suppliers to meet those specifications, is not a new phenomenon. Most large retailers, processors and food services have developed their own detailed product and process specifications. Most take mandatory national (or EU, in the case of European retailers) food safety regulations as a baseline and then build on other specifications in line with their in-house standard sanitation operating procedures (SSOPs). These additional requirements are typically related to quality rather than food safety. Industry sources suggest that they are less likely to include more stringent safety-related criteria than required by national regulations, such as “use by” dates or more stringent requirements in terms of acceptable levels of

pathogens (e.g. *Salmonella*) or contaminants (such as veterinary drug residues). However, they usually include stringent SSOPs or requirements for certification to a food safety management system (FSMS), which include detailed traceability and audit requirements and documentation (see Figure 2).

Retailer product specifications are usually treated as confidential, as they are considered commercially sensitive in what is a highly competitive market (World Bank, 2005). However, the package of specifications is likely to include detailed:

- product specifications: organoleptic and/or sensory and/or taste, metrological (size, block, dimension, etc.), chemical and physical, bacteriological specifications;
- packing and packaging, labelling requirements;
- delivery conditions (where, when, how much); and
- demands for information about the supplier company's safety and sanitary management capacities: SSOPs, safety and quality management process (including details on HACCP and product controls), traceability and recall procedures.

These specifications are typically communicated to the next level down in the supply chain – to processors, brokers or importers, who subsequently translate those specifications to their suppliers.

The practice of buyers inspecting suppliers' facilities and auditing their food safety management systems has occurred for decades in relation to processed (frozen, canned) fish products. Some retailers are now buying direct from aquaculture producers and therefore communicating specifications directly to them. Many have their own audit and inspection requirements. For example, Carrefour, the world's second largest retailer, buys shrimp directly from farmers in Thailand, which involves sending their own inspectors to verify that products and farming practices meet their own standards. In the United States of America, Whole Foods Market (www.wholefoodsmarket.com/stores/departments/aquaculture.php) has developed its own standards for a range of farmed fish and seafood. The standards require that all documentation, records, farms and processing plants be subject to annual inspection (both announced and unannounced spot inspections) by independent third-party auditors, selected by the buyer. Suppliers are required to meet the costs of those third-party audits.

However, most large retailers, commercial brand owners and foodservice industry firms prefer to align themselves to (and require suppliers to be certified to) private standards schemes developed by other bodies, rather than to develop their own certification and verification schemes. Therefore, in addition to their firm-specific product and process specifications, firms might also require their suppliers to be certified to:

- for aquaculture, one or other of the schemes that merge quality and safety with environmental protection, animal health and even social development. For example, Wal-Mart and Darden Restaurants have pledged to buy only farm-raised shrimp from sources certified by the ACC.
- for processed fish and seafood, including from aquaculture, to a national or international FSMS, such as the British Retail Consortium (BRC), International Food Standard (IFS) in Germany, Safe Quality Food (SQF) in Australia, CCvD-HACCP in Holland or DS 3027 HACCP in Denmark.

Adherence to these and other private standards (related to environmental protection, animal health and social development) usually forms part of firms' corporate social responsibility (CSR) strategies, which are marketed both to other businesses as well as to consumers, to enhance the firm's overall reputation.

Safety and quality requirements are supported by multilayered audit and inspection requirements. Independent private certification schemes are attractive to large-scale buyers – requiring third-party certification is cost effective, as it can reduce the need for companies to carry out their own inspection and audit of suppliers.

However, large retailers and food firms may not be equally demanding of all their suppliers or product lines. The pressure on suppliers to conform to stringent private standards depends on the market and the type of product in question. For example, requirements are more stringent for private-label and high-risk processed fish and seafood products than for basic commodity fish and seafood.

The Global Food Safety Initiative

In April 2000, chief executive officers (CEOs) from a range of international retail firms identified the need to enhance global food safety, including by setting requirements for food safety schemes. They were concerned that retailers were having to deal with a multitude of certificates issued against various standards in order to assess whether the suppliers of their private-label products and fresh products had carried out production in a safe manner. They noted that their suppliers were being audited many times a year, at significant cost and with what they perceived to be little added benefit. The Global Food Safety Initiative (GFSI) was developed as an attempt to improve cost-efficiency throughout the food supply chain.

The GFSI's main objective is to implement and maintain a scheme to recognize food safety management standards worldwide, including by facilitating mutual recognition between standard owners, working towards worldwide integrity and quality in the certification of standards and the accreditation of certifying bodies.

The GFSI does not undertake any certification or accreditation activities. Instead, it encourages the use of third-party audits against benchmarked standards. The overall vision is to achieve a simple set of rules for standards, harmony between countries and cost-efficiency for suppliers by reducing the number of required audits.

A guidance document lists key requirements against which food safety management standards can be benchmarked. Those requirements include three key elements: food safety management systems; good practices for agriculture, manufacturing or distribution; and the HACCP system.

A number of relevant standards have been benchmarked as compliant with the GFSI, including:

- BRC (British Retail Consortium) Technical Standard (Version 5);
- IFS (Version 5); www.ifs-certification.com
- Netherlands HACCP;
- Safe Quality Food SQF 2000 Code level two (manufacturing), SQF 1000 level two (primary production);
- GAA BAP (GAA seafood processing standard);
- GLOBALG.A.P IFA (Integrated farm Assurance Aquaculture www.globalgap.org/cms/front_content.php?idart=1446)

The board of the GFSI (Global Food Safety Initiative) is its main governing body and is made up of representatives from the largest retail and wholesale food companies in the world. It is responsible for policy-making and overall decisions. The board is supported by a task force, which acts as a consultation body. Overall, the coalition accounts for more than 70 percent of food retail sales worldwide.

The GFSI is an important development in that it is an attempt to reduce the transaction costs associated with retailers and their suppliers having to apply a multitude of different standards. Suppliers to European retailers report needing BRC certification for the United Kingdom market and IFS certification for the French and German markets. In theory, having a standard benchmarked against the GFSI should mean that there is some form of mutual recognition or equivalence.

In 2009, The GFSI announced that its “vision of ‘once certified, accepted everywhere’ has become a reality” (www.ciesnet.com/2-wwedo/2.2-programmes/2.2.foodsafety.gfsi.asp). Carrefour, Tesco, Metro, Migros, Ahold, Wal-Mart and Delhaize have all agreed to reduce duplication in supply chains through the common acceptance of any of the GFSI-benchmarked schemes. Impacts on suppliers will need to be monitored. While experts have yet to reach a consensus on whether the GFSI has reduced the proliferation of private standards, it has clearly increased awareness of global food safety issues and facilitated cooperation between international retailers.

Traceability

Traceability is *“the ability to trace the history, application or location of that which is under consideration”* (ISO 9000:2005). When considering a product, traceability relates to the origin of materials and parts, the processing history and the distribution and location of the product after delivery.

In the case of food safety, the *Codex Alimentarius* (FAO, 2006) defines *“traceability/product tracing as the ability to follow the movement of a food through specified stages of production, processing and distribution”*.

This definition has been further refined into a regulation by the EU to signify *“the ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated in a food or feed, through all stages of production, processing and distribution”* (EC, 2002).

Traceability can be divided into internal and external traceability. Internal traceability is traceability of the product and the information related to it, within the company, whereas external traceability is product information either received or provided to other members of the supply chain.

Chain of custody is a more specific concept and guarantees not only the ability to trace products but also to ensure their integrity throughout the value chain. In terms of certified fish and seafood, chain of custody includes guarantees that certified product is not mixed with non-certified product.

It is arguably the traceability aspects of private standards schemes that retailers and brand owners find most compelling: they provide valuable guarantees and risk-management functions when there is a lack of confidence in public systems, especially in the food safety arena where control systems in some exporting countries are perceived to be weak. Traceability is especially important in the context of increasingly complex supply and distribution systems and where products pass through multiple hands and even multiple countries before reaching the final consumer. Robust traceability and chain of custody mechanisms also prevent fraud, or non-certified products (of inferior quality or different origins) being passed off as certified product.

Traceability can use either paper or electronic systems, although most are a mixture of the two. Paper traceability systems are widespread and have been used for a long time throughout the supply chain. Electronic traceability uses either the bar code systems or the more recent radio frequency identification (RFID) systems. Bar code systems have been in use since the 1970s and are well established in the food industry. RFID technology uses tags that send identification codes electronically to a receiver when passing through a reading area. These technologies and others such as standardized electronic product coding (EPC) enable products to be traced as they pass along the supply chain.

These tools could be used for public purposes, while related synergies between public and private requirements could be identified to enable cost-efficiencies to be realized.

There is a multiplicity of drivers for traceability in the food sector generally: mandatory food safety requirements, private safety/quality certifications, sustainability claims and business related drivers such as inventory control, promoting efficiencies and communication along the supply chain.

Major issues associated with the development of standards and certification in aquaculture

The impact of standards – safety/quality or aquaculture certifications – is not uniform across markets, species or types of products. However, overall, the impact of private standards in the trade and marketing of fish and seafood is likely to increase as buyers (processors, retailers, food services) consolidate their role as the primary distributors of fish and seafood products, and as their procurement policies move away from open markets towards contractual supply relationships. As the leading retail transnationals extend their global reach, their buying strategies are likely to progressively influence retail markets in East Asia, Africa, Eastern Europe and Latin America. Key issues related to the overall impact of private standards in aquaculture and how they affect various stakeholders require resolution.

Assessing the quality and credence of private standards and related certification

The proliferation of private standards causes confusion for many stakeholders: producers and processors trying to decide which certification scheme will bring the most market returns, buyers trying to decide which standards have most credence in the market and will offer returns to reputation and risk management, and governments trying to decide where private standards fit into their food safety, animal health management and resource management strategies. Transparency and good governance in private voluntary schemes is imperative. A mechanism for judging the quality of schemes is required.

The recently adopted *FAO Technical Guidelines on aquaculture certification* provide guidance for the development, organization and implementation of credible aquaculture certification schemes. They address the following four areas: i) animal health and welfare, ii) food safety, iii) environmental integrity and iv) socio-economic aspects associated with aquaculture production. The guidelines define the minimum substantive criteria for these four areas and cover: i) standard setting processes required to develop and review certification standards, ii) accreditation systems needed to provide formal recognition to a qualified body to carry out certification, and iii) certification bodies required to verify compliance with certification standards (FAO, 2011).

Since the adoption of the *FAO technical guidelines on aquaculture certification*, many aquaculture certification schemes have been aligning themselves with these guidelines and claiming their conformity to them. However, debate continues as to who should be responsible for verifying these claims, what assessment methodologies to use, who should carry out any benchmarking exercise, and for what purpose (e.g. as an assessment tool, a formal benchmark or to achieve mutual recognition). Those are issues that will likely emerge at the next session of the FAO Committee on Fisheries, Sub-Committee on Aquaculture to be held in 2012 in Cape Town, South Africa.

Reducing and/or redistributing compliance costs

Many producing countries have raised concerns regarding the cost of certification, especially for small-scale aquaculture producers. The distribution of those costs is also problematic in the sense that the compliance costs associated with certification to a private standard scheme are borne disproportionately by those up-stream in the supply chain (i.e. producers, processors) rather than those downstream (i.e. retailers, food services, importing processors) where the demands for certification generate. Yet the most robust evidence of price premiums suggests that they accrue to the retailers who demand certification. Should they help foot the bill for certification? Is some redistribution of costs possible, and using what levers? Further international dialogue and sharing of experiences is needed.

Challenges and opportunities for developing countries

Fish and seafood are important income earners for many developing countries. Developing countries are crucial for current and future global supplies of fish and seafood products. In general, certified operators from developing countries tend to be those that are large-scale, involved in more integrated supply chains with direct links to developed-country markets (through equity or direct supply relationships).

Evidence suggests that meeting and maintaining equivalence to mandatory public standards of developed-country markets continues to be more of a barrier to trade than requirements to meet private standards. For developing countries to take advantage of the opportunities presented by private standards, they must first be able to meet the requirements of mandatory regulatory requirements in importing countries. This would create the foundations for future responses to private standards. Any technical cooperation in developing countries would be best focused on getting the public systems right.

Some countries have argued that private standards go beyond relevant international public standards, have no particular scientific rationale and are therefore inconsistent with SPS obligations (WTO, 2008). Some countries fear that private standards could allow importers to impose their domestic policy frameworks and/or other standards (e.g. labour, human rights), offering grounds

to discriminate against developing-country products. Further analysis is required to determine the consistency of private standards with international standards and obligations of the SPS and TBT agreements (WTO, 2011a,b).

While governments have the right to challenge the actions of other governments within the context of the WTO, the grounds for challenging non-governmental actors is less clear. What recourse governments have to challenge these assessments and their implications is still largely unknown. Further inquiry and evidence of the actual effects of private standards on trade opportunities, especially for developing countries, is needed. However, as the boundaries between public and private standards and requirements start to blur, there are implications for trade that need to be closely monitored.

Do private standards complement, duplicate or undermine public regulation and policy frameworks?

Private standards pose key questions for governments: do they duplicate, complement or undermine public regulatory frameworks for food safety assurance and sustainable aquaculture?

Private safety/quality standards are typically based on mandatory regulation and therefore are not likely to conflict with public food safety regulation. Duplication is more likely to be an issue, if not in relation to the content of requirements, then in methods of compliance and verification (including multilevel documentation). There is little evidence to suggest that compliance with private standards facilitates the implementation of public standards. Rather, compliance with public standards provides a baseline for, and is therefore essential for meeting the additional requirements included in private standards schemes. Operators who achieve certification to a private FSMS are mainly those that already run effective food safety management systems.

Private standards overall are unlikely to conflict with public regulatory systems; they are typically either based on public requirements or include compliance with public requirements as part of the criteria for certification. They may duplicate public systems (e.g. food safety, animal health), but they are unlikely to undermine them. Whether or not private standards incentivise better management remains unclear; and whether profit-maximizing private-sector firms or NGOs are the best agents for incentivising better food safety management and sustainable aquaculture also requires further debate.

Are private standards an efficient mechanism for achieving public policy goals of food safety assurance and sustainable aquaculture? If they are compensating for perceived shortfalls in public governance, then they might be simply treating the symptoms when a more effective solution would be to invest in strategies to improve those public systems. Governments need to determine, both individually and collectively, how private-market mechanisms fit into public policy frameworks for aquaculture and how they will engage with them.

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Organic aquaculture: the future of expanding niche markets

Expert Panel Review 4.3

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Abstract

The past 15 years have seen a rise in demand for seafood that has been farmed according to certified organic standards, notably in European countries, led by Germany, the United Kingdom, France and Switzerland. Budding demand is also noticeable among emerging middle classes of transition economies. Part of

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this demand is met domestically or regionally. However, a large proportion of organically certified aquaculture products is produced in developing countries where it is processed and then shipped to their markets overseas. In 2008, total organic aquaculture production globally was around 53 500 tonnes with a total market value of 300 million USD. This was produced by 240 certified operations, of which 72 are situated in China. There were 30 species in certified organic aquaculture production in 29 countries. To date, around 80 different organic aquaculture standards exist, of which there are 18 in the countries of the European Union. Organic aquaculture products usually fetch a price premium over the conventionally produced products, yet with varying dimensions and durability. The trend is for continued steady growth of the organic aquaculture sector accompanied by the establishment of more national standards and labels, in addition to existing global standards.

KEY WORDS: *Aquaculture, Current status and issues, Organic aquaculture.*

Introduction

There is unprecedented growth in the demand for certified organic food, and new areas of organic food production, such as seafood, are proving increasingly popular. In reference to the Codex Alimentarius Commission (2011), organic aquaculture refers to the production processes and practices of ecological production management systems that promote and enhance biodiversity, biological cycles and biological activity (Bergleiter 2003; Bergleiter *et al.*, 2009). It is based on minimal use of off-farm inputs and on holistic management practices that restore, maintain and enhance species diversity and ecological harmony (IFOAM EU Group, 2010; Costa-Pierce, 2010). More generally, the primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people. However, details are often unclear to the consumer, e.g. the exclusion of synthetic fertilizers and genetically modified organisms (GMOs) in the production process (Mansfield, 2003, 2004; Hatanaka, 2010). This contribution presents the current status and issues in organic aquaculture production and markets.

History of organic aquaculture

A detailed account of the history of organic aquaculture and its certification standards is given in Bergleiter *et al.* (2009). The earliest standard was established in 1994 in Austria for common carp (*Cyprinus carpio*) (Table 1). The first national general standards for organic aquaculture were established by France and the United Kingdom in 2000. The first global organic aquaculture criteria were established by the International Federation of Organic Agriculture Movements (IFOAM) in 2000. In the United States of America, the State of California in 2005 banned the labelling of organic aquaculture products pending the establishment of state regulations for such products. Numerous conferences

and workshops enabled practitioners, traders, certifiers and other stakeholders to continually progress the approach.

TABLE 1
History of organic aquaculture*

Year	Species/Issue	Country	Certifying Organization
1994	Common carp (<i>Cyprinus carpio</i>)	Austria, Germany	
1995	Atlantic salmon (<i>Salmo salar</i>)	Ireland	Naturland
1997	Organic aquaculture standard	Australia	National Association for Sustainable Agriculture, Australia
1998	Atlantic salmon	United Kingdom	Soil Association
1999	Shrimp (<i>Penaeidae</i>)	Ecuador	Naturland and GTZ
1999	Blue mussel (<i>Mytilus edulis</i>)	Ireland	
2000	Organic aquaculture standard	United Kingdom	
2000	Organic aquaculture standard	France	Agriculture Biologique
2000	Giant tiger prawn (<i>Penaeus monodon</i>) small-scale farmer groups	Viet Nam	Naturland and SIPPO
2001	Basic organic aquaculture standards	Global	IFOAM
2001	Organic aquaculture standard	Australia	
2002	Tilapia (not species specific)	Israel	Naturland
2003	Aquaculture Group formed	Global	IFOAM
2004	Organic aquaculture standard	Denmark	Økologisk
2005	Organic aquaculture standard	China	
2005	Gilthead seabream (<i>Sparus aurata</i>)	France	
2005	Microalgae	Taiwan POC	
2005	Atlantic cod (<i>Gadus morhua</i>)	United Kingdom	
2005	Ban on labelling of organic seafood	California, USA	State
2006	"Pangasius" (striped catfish, <i>Pangasianodon hypophthalmus</i>)	Viet Nam	Naturland and GTZ
2009	Organic aquaculture legislation	EU	CEC

* CEC = Commission of the European Communities, GTZ = Deutsche Gesellschaft für Technische Zusammenarbeit¹, IFOAM = International Federation of Organic Aquaculture Movements, SIPPO = Swiss Import Promotion Programme.

Source: adapted from Bergleiter *et al.* (2009).

Status of organic aquaculture

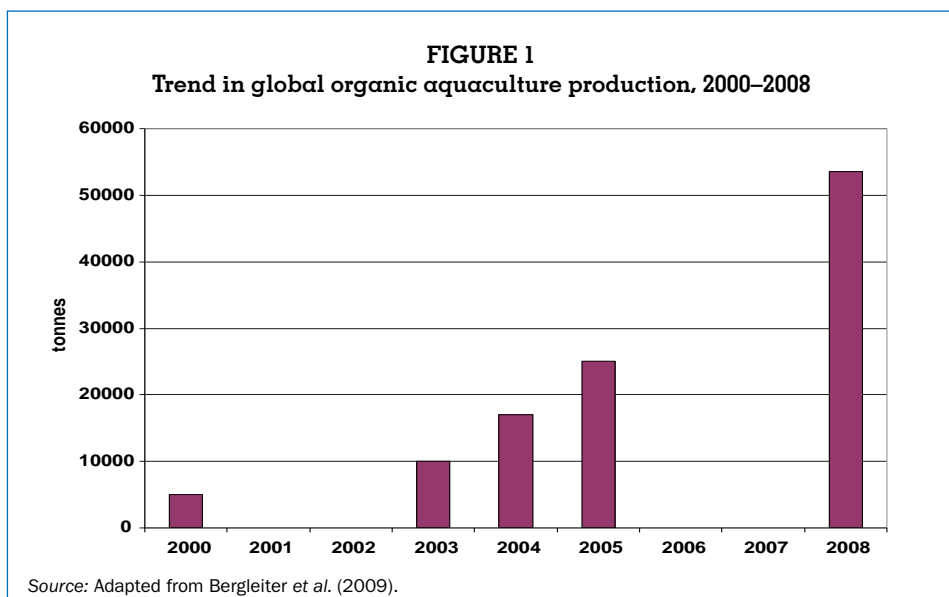
The past decade has seen a rise in demand for organic seafood, notably in Europe, North America and Japan. Budding demand is also noticeable among emerging middle classes of emerging economies. Part of this demand is met domestically (e.g. carp, brook trout (*Salvelinus fontinalis*) or rainbow trout (*Oncorhynchus mykiss*) in Austria and Germany) or regionally (e.g. salmon, cod and molluscs in northern and western Europe, or seabream, seabass, or even tilapia in countries around the Mediterranean Sea). A large proportion of organically certified aquaculture products are produced in developing countries and processed and shipped to their markets. In 2008, total organic aquaculture

¹ Now changed to GIZ = Deutsche Gesellschaft fuer Internationale Zusammenarbeit.

production globally was around 53 500 tonnes with a total market value of 300 million USD (Bergleiter *et al.*, 2009). This was produced by 240 certified operations, of which 72 are situated in China. There were 30 species in certified organic aquaculture production in 29 countries. To date, around 80 different organic aquaculture standards exist, of which there are 18 in the countries of the European Union (EU) (Bergleiter *et al.*, 2009).

Production

The total global production from organic aquaculture increased by 950 percent, from 5 000 tonnes/year in 2000 to 53 500 tonnes per year in 2008 (Figure 1), produced by 240 certified organic aquaculture operations in 29 different countries (IFOAM EU Group, 2010). In China alone, 72 operations have received organic aquaculture certification. Some projections expect total global production to reach 100 000 tonnes by 2011 (IFOAM EU Group, 2010).



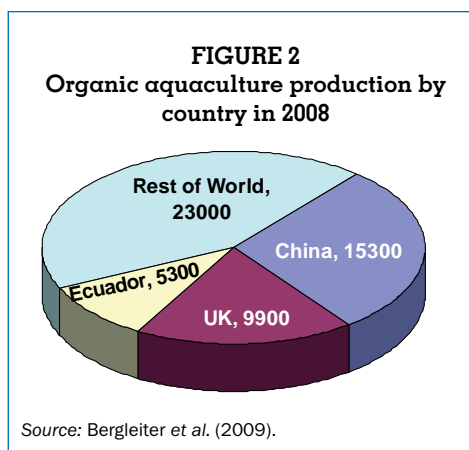
Geographic distribution of organic aquaculture production

Based on data from 2008, the majority (25 000 tonnes/year) of organic aquaculture production is farmed in Europe, followed by Asia (19 000 tonnes/year) and Latin America (7 000 tonnes/year). By individual countries, China leads with 15 300 tonnes/year, followed by the UK (9 900 tonnes/year) and Ecuador (5 800 tonnes/year) (Figure 2).

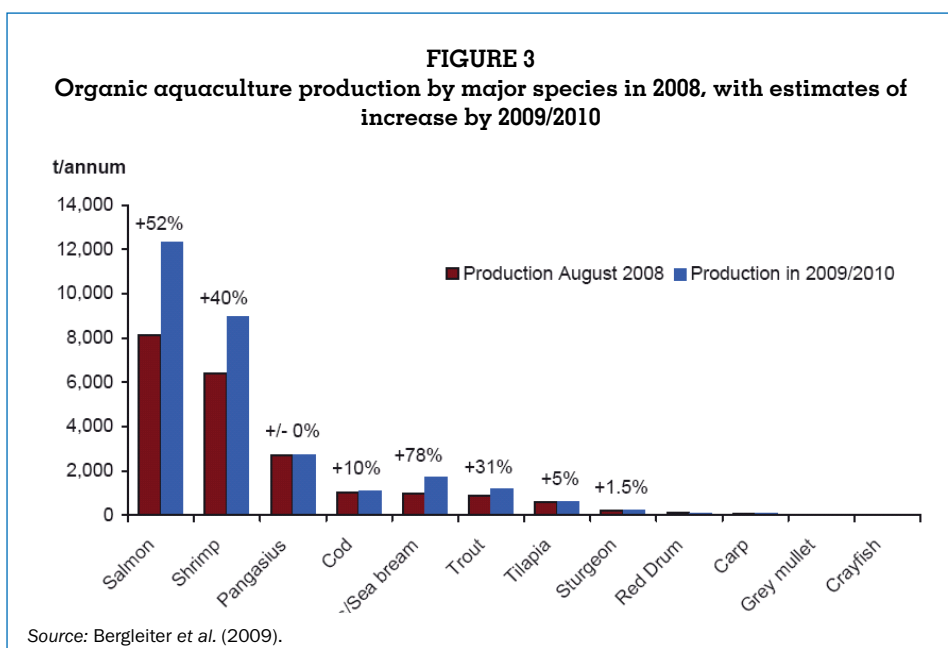
Species in organic aquaculture production

The number of species from organic aquaculture has increased from four species in 2000 to around 30 species in 2009, including at least 15 finfish species, six crustacean species, at least one molluscan species, one holothurian,

one turtle, and at least four species of microalgae (IFOAM EU Group, 2010). For some species of which conventional (i.e. not certified organic) products are sold in large volumes, such as Atlantic salmon (*Salmo salar*) and striped catfish (*Pangasianodon hypophthalmus*, “pangasius”), supply growth of organically produced products has reportedly not been keeping up with demand growth. By species, salmon had the highest production of 16 000 tonnes/year in 2008, followed by “shrimp” (combining *Litopenaeus vannamei* and *Penaeus monodon*) with 8 800 tonnes/year and common carp with 7,200 tonnes/year (Bergleiter et al., 2009).



The main fish species in organic aquaculture are “carp”, “trout”, Atlantic salmon (Tveterås, 2000), “pangasius”, “tilapia”, “seabream”, European seabass (*Dicentrarchus labrax*), meagre (*Argyrosomus regius*) and red drum (*Sciaenops ocellatus*). The main species of shellfish are whiteleg shrimp (*L. vannamei*), giant tiger prawn (*P. monodon*), pink shrimp (*Metapenaeus ensis*), giant river prawn (*Macrobrachium rosenbergii*), blue mussel (*Mytilus edulis*) and Chilean mussel (*M. chilensis*). The three species with the largest production volumes are Atlantic salmon, “shrimp”, and “pangasius” (Figure 3).



Production issues

General

One of the main requirements for species to be eligible for certification under organic aquaculture standards is the requirement for a closed life cycle in captivity, i.e. the prohibition of catching larvae for stocking from the wild. The present acceptance of the giant tiger prawn is due to the consideration that the life cycle has been closed in experimental systems and is gradually in the process of being introduced to the industry, despite technical hurdles.

Further, it is not permitted to commit a new introduction of a species into a country or location in which it previously did not exist specifically for the purpose of organic aquaculture. However, if the introduction occurred at least several years prior to the certification of the farm and the species is considered to be established naturally in the environment and is environmentally benign, then organic certification is permitted.

The maintenance of biodiversity on the aquaculture site is a key aspect of most organic aquaculture standards. Non-destruction of, or even replanting of mangroves in brackishwater coastal locations is a key element of system design and management. The planting of pond dikes with local plant species, particularly for control of dike erosion (avoiding siltation, pond turbidity and subsequently maintaining natural productivity), is a common goal that is not yet met satisfactorily.

Generally, polyculture is the recommended system for organic aquaculture, where several species occupy distinctly separate feeding niches within the aquaculture ecosystem, additively enhancing production per unit area, ideally without additional inputs. This is mostly the case in pond systems in Europe farming common carp (*Cyprinus carpio*) and tench (*Tinca tinca*), but also in extensive and semi-intensive brackishwater systems in tropical locations.

Ponds and cages are recommended rearing systems for organic aquaculture. Tank systems are permitted only for hatcheries and nurseries but not for grow-out operations on farms. A major aspect in the granting of certificates of organic aquaculture is that clusters of net cages as well as the farms themselves should not be spaced too closely together.

The stocking density of cultured species is limited (e.g. by limiting the number of individuals per unit area or per volume of water) in order to approximate conditions as they would occur in the wild and to avoid stress as well as the tendency towards intensification.

The use of mechanical aeration is usually banned, while an exception is made only for mechanical mixing and destratification of the water column for a limited

number of hours per day with a small number of devices. At present, there are no detailed regulations on the required energy efficiency (e.g. the maximum kWh/kg of product from the farming process). Similarly, no requirements are stated for maximum levels of carbon equivalents per harvested product (CO₂/kg), although several standard-setting bodies are evaluating the feasibility of such criteria and even product labels.

Several organic aquaculture standards require the monitoring of effluent quality, with the stated goal of avoiding negative impacts on the surrounding environment. The improvement of the ecological status of the ponds themselves, notably the benthos, is a requirement of some standards. Recent studies have shown that the biodiversity within and around aquaculture farms (notably shrimp farms) increased significantly after organic certification in comparison to the prior situation when operated under conventional methods, or in comparison to conventionally operated farms in the vicinity.

Several organizations have expanded their standards that were originally more focussed on ecological criteria to include social criteria. In the future, the addition of aspects of animal welfare is expected.

Reproduction, fingerlings and larvae

As the provision of juveniles for stocking through controlled conditions is of major concern, most standards place a major emphasis on criteria for hatchery operations. The aim is to achieve a closed cycle and to avoid the collection of seed from the wild. In certain countries or locations with newly established, pioneering organic aquaculture operations, the volumes of hatchery production according to organic criteria have been limited. The additional sourcing of juveniles from conventional hatcheries is therefore permitted under certain conditions. By some definitions, for operations having to rely on such bought-in juveniles, a minimum of two-thirds of an animal's life span should have been under conditions certified as organic by the time of harvest.

Restrictions also exist for methods to induce spawning, for example, on the use of hypophysation in fish and the manipulation or ablation of eyestalks in crustaceans. Hormonal sex-inversion is not permitted. The induction of polyploidy in the reproduction process as well as the use of polyploid animals in organic aquaculture is not permitted. The farming of GMOs is also not permitted.

For farmers, the fluctuations of prices of juveniles from certified organic sources has been a challenge. Premiums of between 0 and 24 percent annually pose risks in cost calculations.

Health

Organic aquaculture principles aim at reduced instances of disease. Likewise, if disease does occur, the costs for treatment are expected to be reduced due

to the extensive nature of the operations and the expected hardiness of the less-stressed fish.

In net cages, the use of chemicals for sea-lice treatment is not permitted. As a successful remedial measure to treat sea lice, cleaner fish (wrasse) are promoted and have induced the development of own wrasse farming operations to supply these to the net cage farms.

According to most private organic aquaculture standards (e.g. Naturland e.V.), antibiotics are not permitted in invertebrates (e.g. shrimp), whereas the 2009 EU regulation is less stringent in this regard. The use of antibiotics is not prohibited in fish, but after use the treated fish cannot be sold with a label as organically certified. The use of vaccines as well as probiotics is permitted.

For predator control, measures should not harm the predators. Nets over ponds or cages are recommended for control of birds, while for the control of otters and seals non-harmful repellents should be used.

To control unwanted fish fry in ponds, such as those of predators or non-target competitors, natural plant extracts are permitted. However, the use of detergents or antifouling chemicals to treat nets of cages is not permitted, as these are considered harmful to the environment as well as to the cultured organisms.

Feed

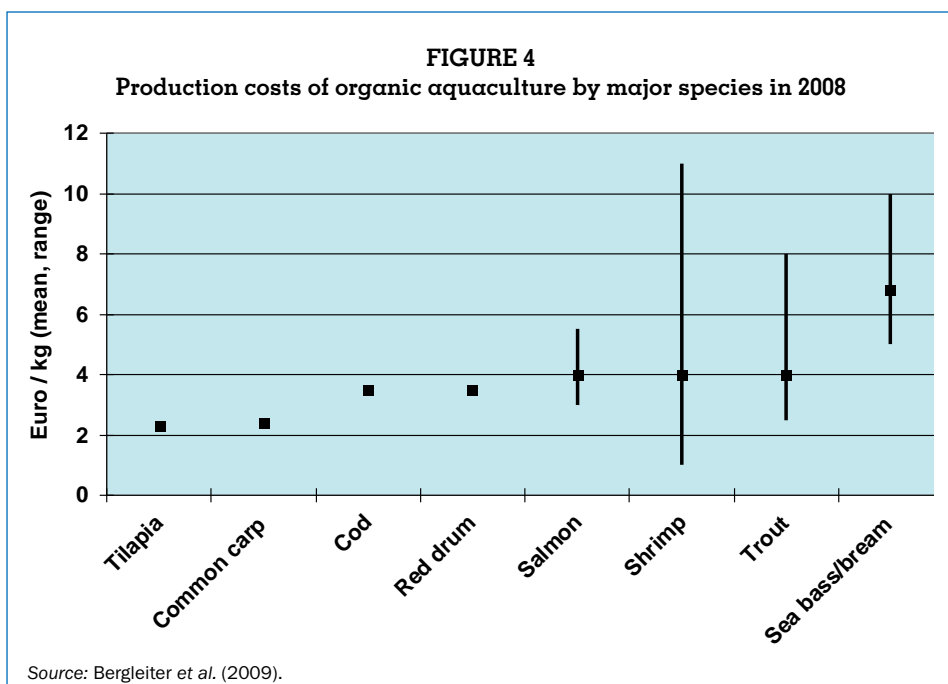
The most salient issue in organic aquaculture production is the existing bottleneck in supply of certified organic feed. Even if organic carp farmers in Europe and extensive giant tiger prawn producers in Southeast Asia have little difficulties to satisfy their modest requirements for external feed, organic net-cage and semi-intensive pond farms are facing a drastic increase in feed prices, particularly if organic vegetable feed ingredients (e.g. soy, cereals) have to be sourced from global markets. Global demand for certified organic feed ingredients for aquaculture and agriculture far outstrips supply, resulting in very high prices and consequently, high production costs. Furthermore, organic principles should aim at reducing environmental costs of long-distance shipment (Pelletier and Tyedmers, 2007). However, in a country with only one or a few organic aquaculture farms, the initiation of organic agriculture feed projects and the establishment of the first local organic aquaculture feed mill is a challenging process, requiring high levels of commitment by, and cooperation between different sectors (e.g. aquaculture, agriculture, feed production). First promising projects of this kind have developed in Brazil, India and Bangladesh.

In many countries, existing feed mill operators hesitate to undertake the part-time production of relatively low amounts of feed due to the stringent requirements in preparing machines between runs of organic and non-organic feed to avoid contamination. Additionally, the sourcing of agricultural ingredients

at the national or local level which satisfy the requirements of organic labels can pose serious obstacles for start-ups, notably in developing countries.

Production costs

Costs of production are higher where feed costs are higher and the volume of production is relatively small yet the area of the operation is larger due to the more extensive nature of the organic farming system. Examples of economic feasibility studies have been conducted for organic shrimp, freshwater prawn and freshwater fish (INFOFISH, 2011). Figure 4 shows the production costs of organic aquaculture for major species in 2008.



Certification of smallholder farmer groups

Certification of smallholder farmer groups has a long history in organic agriculture, such as in coffee and tea farmer cooperatives. Today there are certified organic shrimp farmer groups in Bangladesh, Costa Rica, India (Phillips et al., 2008; NACA, 2010), Indonesia and Viet Nam (Camillo, Poisson and Serene, 2004; Mueller, 2004). This can be communicated to consumers who find additional appeal in equitable remuneration arrangements (e.g. “fair trade”).

These arrangements are usually initiated by seafood processors or by seafood traders or importers in developed countries. They take a long-term perspective to such linkages. Contract farming arrangements with price guarantees and production specifications are a common feature. Smallholder farmers require considerable effort to become organized. In some countries (e.g. Viet Nam), the registration of groups forms the legal basis for joint operations.

For adaptation of farms to the criteria of the organic standards, as well as to cover the costs of the advisory services that guide the transition, farmers often need to make investments which are difficult if not impossible for smallholders. In such group formations and collective arrangements, the processing or exporting partners often cover the costs. These also arrange for the provision of better quality inputs such as disease-free larvae or fingerlings, as well as good quality feed. They arrange for training of the farmers on the necessary organic farming criteria. The viability of smallholder group arrangements growing a highly perishable product that also has such stringent criteria as organic aquaculture is highly dependent upon a functioning internal control system (ICS). These are tedious, time consuming and costly to establish and successfully operate, but experience has shown that farmers appreciate the benefits of equitable arrangements and adjust their management systems accordingly. The groups also constitute nuclei for further up-scaling (Umesh *et al.*, 2010; Subasinghe and Phillips, 2010).

Processing of organic aquaculture products

Farmed organic aquaculture products are usually sold to local processors who have contracts with traders and/or importers. Farms usually grow products according to specific criteria (e.g. individual fish size, harvest schedule) demanded by the market and conveyed by processors. Processing is also conducted according to market demands and local capacity. For example, in shrimp processing, these demands can range from whole freezing over peeling, deveining and blanching to breading, saucing and packing as ready meals. In some cases, where local processing capacity is not well developed, raw products are frozen, shipped and final-processed in another continent. There the final product can range from repackaged individually quick-frozen shrimp or fish, to marinated products, to ready meals, including organic pizzas with a few shrimp or bits of salmon sprinkled on them. Some producers have established their own processing facilities, given unwillingness by local processors to interrupt their processing lines of conventional product and clean the entire system in order to process a batch of organically certified product. For processing, an own set of standards and criteria exist, and processors also need to undergo a certification process, with ensuing regular audits. Ideally, with adequate volumes of production and marketing, processors maintain separate lines for organic products as well as conventional products in their facilities.

The entire production chain requires documentation to ensure full traceability. In the processing facilities, the organic standards have specific criteria on the use of detergents and for pest control substances. Anesthetization of vertebrates before slaughter is mandatory. Certain additives are either restricted in use or prohibited (e.g. metabisulphites, phosphates, and anticaking agents). The ingredients used in the processing, such as breading and spices, must also be organically certified.

Organic aquaculture products

Today, organically certified aquaculture products are marketed in a wide range of processed forms, e.g. fresh (chilled, on ice), frozen, smoked, marinated, modified atmosphere packed (MAP), all the way to value-added products. By far the most common form is frozen product (with fresh-thawed product displayed on ice in the shops), but the further-processed value-added forms (all the way to ready meals) are gaining market share.

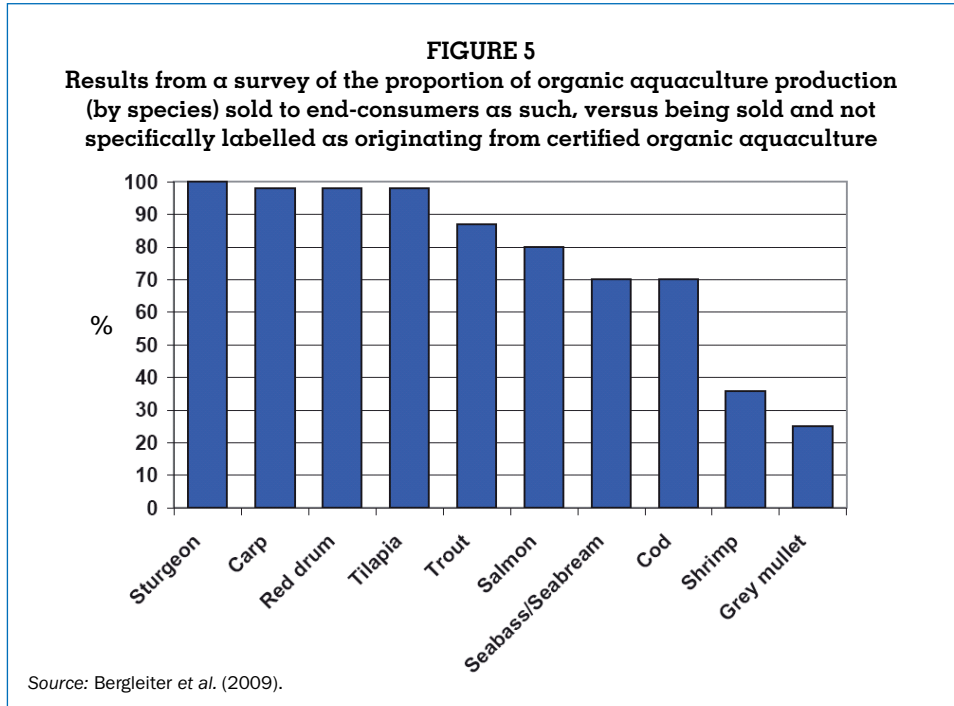
Marketing of organic aquaculture products

The total market value of organic aquaculture products was estimated 300 million USD in 2009. The major markets are European countries, led by Germany, the UK, France and Switzerland. Here features of an evolving market are observed, such as increasing sales volumes, growing competition in increasing numbers of new outlets and market channels, and increasing pressure to decrease prices. The United States of America is considered to have a large potential once regulations are passed by the USDA. Other countries, particularly in East and Southeast Asia, are showing gradual expansion of organic aquaculture markets; however, these are characterized by high prices, low sales volumes, little or almost no competition and the need to invest in marketing and create consumer awareness of organic aquaculture products.

Marketing channels are species dependent and also reflect characteristics of the respective region of production and consumption. Marketing of seafood in general and of organically certified seafood in particular is characterized by a diverse web of products and markets. These can range from sales at the farm gate or in small specialized organic food shops to supermarkets and discounters. A recent trend has been the strong increase in market share by the latter, at somewhat discounted prices, where a large share of the volume growth of the past decade has taken place.

There are numerous intermediaries in the seafood sector in general, and more so in the organic seafood sector. Due to greater agility, all intermediary players can appear at the processors' or even farmers' doors: buyers, agents, reproducers, wholesalers and retailers. Here various criteria influence the decisions as to the sale of products, either as organically labelled or, despite its organic origin, as conventional product, which includes the novelty of an organically certified seafood species on the market (Figure 5).

There is a large volume of onward product trade, e.g. within the EU, where some countries traditionally have strengths due to a previous engagement in the seafood sector. Own-branding by retailer chains is steadily expanding by volume, all the way to whole purchases of processing facilities. In this respect Asian countries are emerging strongly, notably China, Hong Kong SAR, Republic of Korea and Taiwan POC.



Consumer perspective

In the sustainability, as well as the expansion of the organic seafood sector, the perception of the consumer is the driving factor (O’Dierno *et al.* 2006; Stern 2007). The continuous evolution of the standards as well as products and their diversification are important aspects. A suite of attributes characterize organic products in the eyes of the consumer. These can be grouped into categories of environment (“naturally grown”, “sustainable”), health (“healthy”, “pure”, “no additives”, “good for my young children”), consumption (“taste”, “texture”), social (“fair”) and lifestyle (“special treat”). These have been summarized by some under the descriptor of LOHAS, or Lifestyle of Health and Sustainability, as is currently pervasive.

It is important to consider that this trust in organic products in general, and in organic aquaculture products in particular, is fragile. Much depends on the credibility of the sector and its variety of products and farming systems, as the consumer is highly sensitive to scandals. Still, consumer surveys show that doubts persist about the true origins of products, and whether all of the products on the market are truly from certified organic farms.

To date, the sector has maintained a perception of “honesty” and “credibility” among consumers. The sector relies on specific communication avenues and messages to maintain a perception of realistic, moral, ethical business, with high regard for environmental, health and social criteria. The sector maintains constant communication with the consumer through a wide variety of channels

and media to maintain this perception, yet there is general understanding that much more should be done by the organic aquaculture sector.

Across the organic agriculture sector, a clear distinction should be made between categories, i.e. grains and cereals, dairy products, fruit and vegetables, meats and fish (or “seafood”) in the order of purchased volume by consumers, with the first being the highest. Meats and seafood are presently, and for the foreseeable future, the categories with proportionally lesser sales and consumption volumes for organically certified products. However, across all categories a price premium usually exists, which reflects a “willingness to pay” by consumers.

Organic certification standards and labels

Around 80 different organic aquaculture certification standards exist, both public as well as private, of which those with the greatest number of certified farms are Naturland, AB France and Bio Suisse. Favoured by broad (general) compatibility among standards, farms may obtain certification according to more than one label, in order to access a greater variety of markets. However, the greater majority are certified according to one label only. As of 1 July 2010, the new EU organic aquaculture implementing rules are applicable. These constitute a consensus “minimum” standard, while other existing standards are stricter in their requirements. One of the issues of debate is that there is no limit to the percentage of fishmeal in feeds for coldwater species such as trout, Atlantic salmon and cod, whereas for warmwater species such as shrimp, tilapia and pangasius there is a permissible fishmeal limit of 10 percent in their organic feeds, while for tilapia, fishmeal in the feed is even completely forbidden (CEC, 2009; IFOAM EU Group, 2010; Klinkhard, 2010).

Today, several specific and relatively precise certification standards for organic aquaculture production (i.e. hatchery, feed, grow out) and processing exist which aim at achieving optimal, sustainable agro-ecosystems. A number of private organic aquaculture standards (e.g. Naturland, Soil Association) also include obligatory social criteria, some of them even including the option for a “Fair Trade” certification (e.g. the Naturland “Organic plus Fair” scheme). Impartial organizations take part in the inspection and certification process to ensure adherence to the relevant production and processing standards.

The role of IFOAM

The International Federation of Organic Agriculture Movements (IFOAM) is the world umbrella organization of the organic farming movement. IFOAM runs the International Organic Accreditation System (ISOAS) and the International Basic Standards (IBS) criteria. IFOAM is further represented in policy-setting procedures, e.g. the EU and the USDA. IFOAM is a member of the International Social and Environmental Accreditation and Labelling Alliance (ISEAL), the global association for social and environmental standards. IFOAM has a fostering and harmonizing role, for example regarding the mutual recognition of certifications.

Inspection and certification bodies

Although standards are set by private, national or intergovernmental organizations or institutions, the inspections or audits of the farms are conducted by independent “third party” inspection bodies (IBs) who are hired to provide the service, usually at the recommendation of the standard-setting body. The actual certification is conducted by certification bodies, i.e. the institutions setting and maintaining the standards. These are normally accredited according to ISO 65 according to their operational procedures of standard setting, commissioning third-party IBs to conduct independent audits and annual inspections. A suite of audit rules, manuals for interpretation of the standards and conduct of inspections and audits, as well as checklists for the inspections and audits need to be prepared for each standard. Inspectors need to be trained in the specifics of the respective standards and their interpretation, so that they meet necessary qualifications. Certification bodies as well as IBs maintain outreach offices and liaison offices through partner organizations. In the implementation of the inspection, auditing and certification process, cost efficiency is a major factor for consideration in the design of these services. Several countries have formulated national standards and strategies for up-scaling of organic aquaculture, for example, Thailand (Ruangpan, 2007), which reflects government commitment and support to the growth of the sector.

Organic aquaculture as rural development

The recently completed project financed by the Common Fund for Commodities involved organic farms in Thailand (shrimp), Myanmar (shrimp) and Malaysia (tilapia and shrimp). In Thailand, the project was successful in obtaining organic certification for the involved stakeholders and in establishing contacts with buyers in international markets. In Malaysia and Myanmar, good potential was identified for the relevant parties. The main obstacle encountered was the difficulty in obtaining organic feed at a reasonable cost. On the plus side, domestic and regional demand for organic aquaculture products was much stronger than anticipated².

Despite the characteristic of a niche market, organic aquaculture is considered to have opportunities for food security and poverty alleviation when implemented by rural farmers (Funge-Smith and Halwart, 2004). In terms of small and medium-sized rural businesses, successful bilateral development initiatives in Latin America and Asia with shrimp and pangasius prove that certification (and organic certification in particular) has had positive effects on aquaculture industries. These in turn have led to improvements by other players and stakeholders in the local industries, and have been either locally expanded,

² Presentation by T. Singh on *Farming and certification of organic and “chemical-free” fishery products under the CFC/FAO/INFOFISH Organic Aquaculture Project* presented at the Asia-Pacific Regional Workshop on “Organic Aquaculture Development in Myanmar, Thailand and Malaysia”, 3–6 March 2011, Bangkok, Thailand.

nationally up-scaled or even transferred to neighbouring countries, with resulting viable small and medium-scale businesses supplying local and export markets (Nolting and Prein, 2008).

Future outlook

A census of organic aquaculture conducted in 2009 (Bergleiter *et al.*, 2009) showed global organic seafood production to be approximately 55 000 tonnes. Since then, new products have been certified and in 2011, there may be about 80 000 tonnes of certified organic seafood, altogether. World aquaculture production (excluding aquatic plants), is 52.5 million tonnes (FAO, 2010); thus, only 0.1 percent of total production is currently certified and marketed as organic. However, the prospects for strongly expanding this tiny niche are good (see also Bergleiter, 2011):

- A considerable portion of the world aquaculture industry is already producing very close to, or even in congruence with, organic principles. However, this has not translated into formal certification. This is particularly true for bivalve shellfish and seaweed culture, which in general are “no input” systems. The areas where the industry does not yet meet organic standards are mostly related to the recycling or re-use of ropes and other disposable culture materials and to appropriate siting of farms in areas with the best water quality. Both these issues are increasingly being tackled by national and international legislation so that organic group certification of large areas seems within reach.
- Cyprinids (carps) are by far the largest family of farmed finfish. These are mostly produced by Asian family enterprises and consumed locally. Typically, they apply organic production principles, often using polyculture systems that include rice, ducks or pigs, and give a general priority to fertilizing rather than feeding. Nevertheless, these systems would still face several obstacles if they were to seek organic certification, mainly due to gaps in quality management and the traceability of the different inputs. Ongoing urbanization and increased domestic exports to the big cities are likely to lead to much more attention being paid to food quality and safety, which will result in moves towards standardization and reliable certification.
- Shrimp and prawns are the most important aquaculture export items from many southern countries. In Southeast Asian countries, a large proportion of these are farmed in extensive, low or no-input systems that are very suitable to be converted into certified organic operations. The major challenge here is to establish internal control systems enabling large numbers of small-scale farmers to run their operations in accordance with agreed standards (e.g. regarding mangrove protection and reforestation). At the moment, there are certified organic shrimp farms in Viet Nam, Bangladesh, India, Indonesia and Thailand, which volume-wise represent only a fraction of the organic potential in these countries. In South America and Madagascar, shrimp companies are usually large, integrated enterprises which have the ability

- to implement organic standard requirements directly and to take immediate action along the whole production chain. The farms operate using a semi-intensive model (i.e. feeding the shrimp, with additional fertilization of the pond). The main challenge for organic candidates here will be to source certified organic vegetable feedstuff at a reasonable cost. This is being tackled by initiating pilot organic projects producing certified organic manioc, rice, soy and corn as feed ingredients in these countries.
- Salmon is a very sought-after aquaculture product and, due to feed and energy costs, prices are steadily increasing. Over the past 15 years, organic salmon has become well established in European markets. In Ireland, certified organic production already makes up more than half of the total salmon volume, and strong market demand is currently pushing other countries to follow this example. The requirements for farming organic salmon are clear and widely accepted, with the goals of increasing product quality and environmental performance. Yet these standards are also demanding and expensive to meet. As long as there is a demand for salmon that are grown under less strict environmental conditions, the two major salmon-producing countries, Chile and Norway, will be reluctant to contribute to the organic momentum.
 - The other main organic aquaculture species can be located somewhere between the scenarios given in this overview: The Mediterranean species (seabream, seabass and meagre) can be compared to organic salmon, but have not yet had the same duration of mainstreaming. Organic trout and char producers in Austria, Germany, the UK and Switzerland are usually smaller farms who still mainly focus on local markets. Delivering to large retail markets remains a challenge to them. Organic tilapia and pangasius production can be compared to semi-intensive shrimp farms; the critical factor in organic conversion is obtaining a supply of certified organic feed from, as far as possible, domestic organic agriculture.

In the future, the largest increases in production volume of organic aquaculture products are projected for Atlantic salmon and “shrimp”, as well as certain finfish species that are presently in undersupply (e.g. tilapia). The global market value of organic aquaculture is expected to increase by 40 to 60 percent over the three years between 2009 and 2012, surpassing a total value of 640 million USD in 2011, focussed, however, on a few highly developed markets, notably Organisation for Economic Co-operation and Development (OECD) countries. Although considerable scope exists for development of organic agriculture markets in developing countries due to the increasing numbers of middle-class consumers, experience has shown that the initial growth and expansion is in other organic food categories, such as grains, dairy products, fruit and vegetables, and only in a secondary phase in meats and aquatic products. Raising consumers’ information level on aquaculture issues in general and creating awareness of the organic initiatives seem critical for stable market development. Numerous successful examples show that joint ventures or

long-term contractual arrangements between retailers and producers contain supporting arrangements and create incentives.

For stabilizing global growth of this initiative, better strategies will have to be developed to avoid the bottleneck of insufficient organic aquaculture feed supply, notably in the budding semi-intensive organic aquaculture sector in developing countries.

At the same time, the organic market presents an attractive option for extensive aquaculture producers, particularly in the case of extensive and integrated shrimp production in Southeast Asia, where farmers operations are already working very close to organic principles. The challenge here is the vertical integration of supply chains (hatchery-feed-farm-processor-exporter), granting full traceability as a prerequisite for a valid certification.

Benchmarking of existing (and also conventional) labels and standards and cross-accreditation should be progressed in order to enable farms to access additional market channels without the need for new and costly inspection and certification procedures.

By 2015, a total value of 1.25 billion USD for organic aquaculture products has been forecast (Bergleiter *et al.*, 2009). For some finfish such as tilapia, there is presently an undersupply of organically certified product. Such phenomena occur when new standards are created and markets as well as producers have not established a balance of demand and supply. However, further diversification of species under organic aquaculture certification is needed and even expected. In the future, the feed bottleneck will need to be solved. Harmonization of organic aquaculture standards will occur. However, given that standards are a competitive business that is partly governed by national perspectives, it is expected that a diverse array of standards and certification bodies will continue to exist. The United States Department of Agriculture (USDA) is lagging behind international developments in the establishment of regulations for organic aquaculture. Considerable expansion of organic aquaculture markets is projected for China, Republic of Korea and the Russian Federation.

Conclusions

Organic aquaculture and markets have met the expectations and commitments expressed in the Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000. (NACA/FAO, 2001), including: improved environmental sustainability, strengthening of institutional support to implement transparent and enforceable policy and regulatory frameworks, application of rules and procedures, application of innovations in aquaculture, better management of aquatic animal health, improved nutrition in aquaculture, improved food quality and safety, and the promotion of market development and trade.

In the future, the efficiency of organic aquaculture value chains needs to be increased. The presently existing feed bottleneck needs to be removed. One option is through contract farming of certified feed ingredients. A workshop with all relevant stakeholders could be conducted to address the feed bottleneck problem. In the future, joint ventures will be established between retailers and producers, and these will result in greater efficiencies and market-aligned production, as well as ensured and sustainable returns for farmers. Micro-insurance schemes for organic aquaculture farmers will need to spread and become a mainstay, as has happened in other agriculture production sectors.

Consumers will need to be educated about the criteria of organic aquaculture, notably in new and hitherto untapped markets, but also in traditional markets consumers need to be continuously informed. Policy support needs to be provided by national programmes for the expansion and upgrading of national standards and their harmonization with existing global labels. In this vein, the benchmarking of existing standards needs to be conducted, which can lead to their harmonization. On the other hand, the addition of “fair trade” criteria to organic aquaculture standards poses a considerable market opportunity already voiced by importers and traders. Finally, there are no research and development facilities for the conduct of applied organic aquaculture research and demonstration of systems. The establishment of such facilities in key environments would further the scientific basis, credibility and expansion of the sector.

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Investing in knowledge, communications and training/extension for responsible aquaculture

Expert Panel Review 5.1

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Abstract

Knowledge has always been critically important to the development of aquaculture whether we are talking about the earliest aquaculture innovations starting in Asia or the more recent challenges confronting the sector worldwide. This panel reviewed selected national and regional case studies. Key topics for discussion include knowledge production and its communication and use (e.g.

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in new training and extension approaches) among the changing audiences (as aquaculture continues to attract an increasing variety of new stakeholders), and dealing with a widening set of change processes in recent times, often involving a complex mix of governance and social change challenges. We go on to suggest that aquaculture policy-makers, and stakeholders in general, need to better understand knowledge processes such as knowledge translation (implementation), knowledge networks (e.g. the role of farmers' associations) and the use of knowledge platforms and brokers, all aimed at more effective dissemination and adoption of knowledge. Knowledge management by most stakeholders will become increasingly critical to the sustainable development of aquaculture and its movement towards attaining the goals set out in the Bangkok Declaration a decade back.

KEY WORDS: *Aquaculture, Communications, Extension, Knowledge, Sustainable aquaculture, Training.*

Background

Knowledge is defined in the Oxford Dictionary as “familiarity gained by experience or a persons’ range of information” and so forth. In the modern context, obtaining, storing, disseminating and sharing of knowledge, in various forms and means and in diverse repositories, have become enormous tasks. As knowledge is acquired through innovations and experiences, its management is becoming increasingly crucial for sustainable development. To set an initial broader context, we begin with two thoughtful quotes on knowledge management strategies:

“Our ability to learn what we need for tomorrow is more important than what we know today”

George Seimans (Seimans, 2005),

and

“Experience has long been considered the best teacher of knowledge. Since we cannot experience everything, other people’s experiences and hence other people, become the surrogate for knowledge. I store my knowledge in my friends is an axiom for collecting knowledge through collecting people.”

Karen Stephenson (Stephenson, 1998).

Knowledge has been critically important to the development of aquaculture, as in all human endeavours, irrespective of whether we are talking about the earliest aquaculture innovations starting in China or Egypt millennia ago or the more recent breeding and disease challenges in the 1970s and 1980s, now continuing into more recent times. However, few scholarly investigations have attempted to probe aquaculture development through a knowledge lens. Other sectors such as business are examining knowledge in detail (see for example the knowledge economy thinking), the health sector (as we will discuss later)

and the information and communications technology (ICT) stakeholders are examining knowledge sharing and management¹ thinking in a variety of very interesting and novel ways. We argue below that the aquaculture sector needs to address this issue and particularly to do so around some of the more recent knowledge translation thinking², all as part of the move to improved sustainability in the aquaculture sector and meeting the goals set in the *Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000* (NACA/FAO, 2001a). Knowledge translation thinking has developed in the health sciences and provides a very useful model for aquaculture to mimic, around what we call working at the “aquaface”; a concept that we will return to later in this review.

Some knowledge history: ten years ago, the Bangkok Declaration 2000 and the coming decade

Looking back to the Food and Agriculture Organization of the United Nations (FAO) Technical Conference on Aquaculture in Kyoto in June 1976 (FAO, 1976) and the past global aquaculture conference, the Conference on Aquaculture in the Third Millennium, held in 2000 (NACA/FAO, 2001b), it is clear that there has been recognition of the importance of networking and related forms of knowledge sharing and learning. However, these conferences really did not look at knowledge *per se*. For instance, we note that the three main elements of the Bangkok Declaration and Strategy (NACA/FAO, 2001a) with a strong link to our panel’s focus include: 3.1 Investing in people through education and training; 3.2 Investing in research and development; and 3.3 Improving information flow and communication. However, it is difficult to provide much precision on changes in the last ten years based on this material. In general, indicators of change and related quantitative data on key aquaculture change processes are difficult to obtain, and we suggest that a re-examination of these issues with a view to developing quantifiable indicators for the next decade (in preparation for Aquaculture 2020?) should be examined. Later in this paper, we go on to provide some qualitative observations on some of the changes we see taking place that could provide some guidance for such an approach.

Globally, knowledge generation is increasing exponentially, and aquaculture is no exception. Identifying and applying the needed knowledge, and even just keeping pace, present continuing challenges for most of us, and this is particularly so for many of our newer aquaculture stakeholders, especially in our globalized world where communication channels have so rapidly increased and diversified. It is difficult to obtain reliable data on knowledge production, but some rough estimates are as follows. In terms of the science side of our aquaculture knowledge base, there were approximately 42 “aquaculture journals” in a 2006 list³. However, we assume that most of us are accessing a wider set of knowledge

¹ Knowledge management (KM) comprises a range of strategies and practices used in an organization to identify, create, represent, distribute and enable adoption of insights and experiences.

² See for example <http://web.idrc.ca/openebooks/508-3>

³ See “aquaculture journals”, <http://ag.arizona.edu/azaqua/extension/journals.htm>

sources than this focussed journal list. Recent estimates by Bjork, Roos and Lauri (2009) using 2006 data, suggest that the number of science journals (in fact using a reasonably wide view of all sciences, both social and natural) has reached 24 000. Therefore, to give some relative measure, aquaculture journals represent roughly 0.008 percent of this total. More importantly, the total number of articles published in scholarly journals was approximately 1 350 000 and increasing rapidly. Clearly the supply of knowledge is now enormous and growing rapidly, and this has a number of implications.

One of the most persuasive knowledge factors is the shrinking half-life of knowledge. The “half-life of knowledge” is the time span from when knowledge is gained to when it becomes obsolete. Half of what is known today was not known ten years ago. The amount of knowledge in the world has doubled in the past ten years and is doubling every 18 months according to the American Society of Training and Documentation (ASTD)⁴. To combat the shrinking half-life of knowledge, organizations have been forced to develop new methods of deploying instruction (Gonzalez, 2004). Our look at the Conference on Aquaculture in the Third Millennium (NACA/FAO, 2001b) and our plans for 2020 should be viewed with these key concepts in mind.

Aquaculture knowledge management

Is it opportune to re-examine our approach to knowledge? Knowledge management (KM) questions such as: Are most stakeholders able to access the knowledge they need? How might this access be improved? How well do we understand our approach to KM? Coming back to some of the goals of the Phuket conference (NACA/FAO 2011), how well does this knowledge fit with our objectives related to the goals of the Bangkok Declaration? In the following sections, we now move on to examine two aspects of KM around knowledge connectivity/networking thinking and knowledge translation.

Knowledge use, strategic influence and longer term change processes

We are starting to see some analysis in this area, and perhaps we need to be thinking more about influence and impact in our aquaculture KM. Interestingly, Hewitt *et al.* (2009) looked at most of the major American fisheries journals, including some in aquaculture, both in terms of citation-based measures of influence of selected journals as well as cost effectiveness. But most of this analysis does not give us much guidance in terms of our Bangkok Declaration thinking.

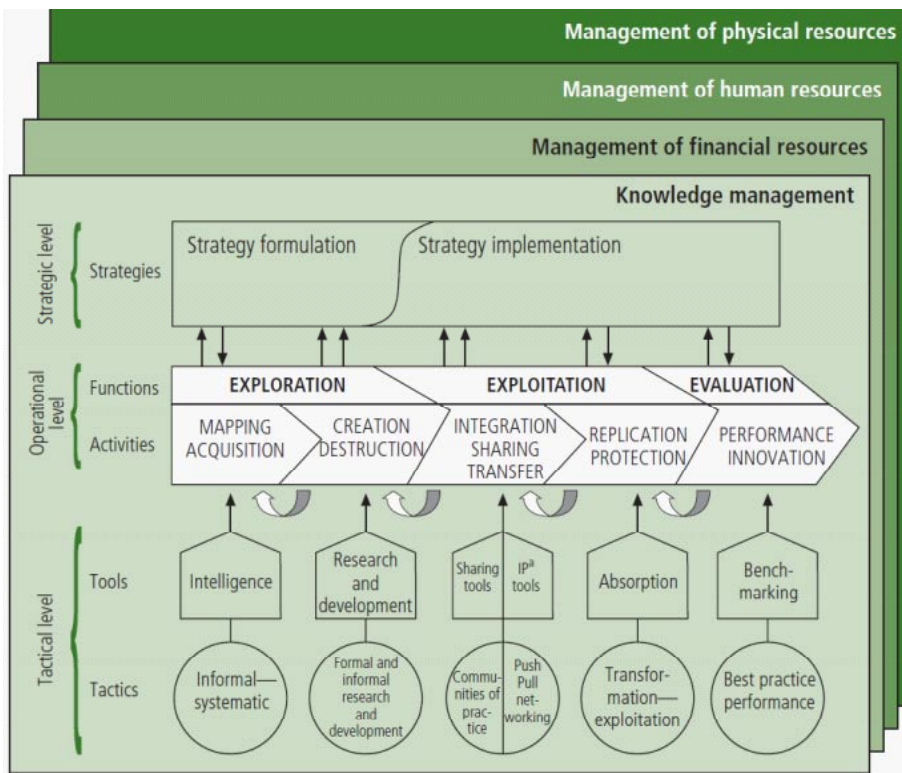
The health sector offers a lot of interesting case material that might provide useful guidance for further work on aquaculture. Value-chain thinking seems to be in vogue of late, and there is increasing examination of this conceptually

⁴ www.unt.edu/benchmarks/archives/2004/september04/eis.htm

in other sectors of KM, for example in health (see for instance Figure 1 below which illustrates some of the parts of the KM chain as seen in the health sector). This thinking provides one set of health-based KM examples that seek to subdivide the approach into tactical, operational and strategic levels against formulation to implementation thinking.

Finally, in terms of knowledge use, we suggest that strategic influence (see, for example, International Institute for Sustainable Development (IISD) strategic influence thinking) should receive greater attention in terms of how to more effectively use our knowledge in reaching various users and promoting more sustainability thinking.

FIGURE 1
The knowledge-value chain according to Landry *et al.* (2006)

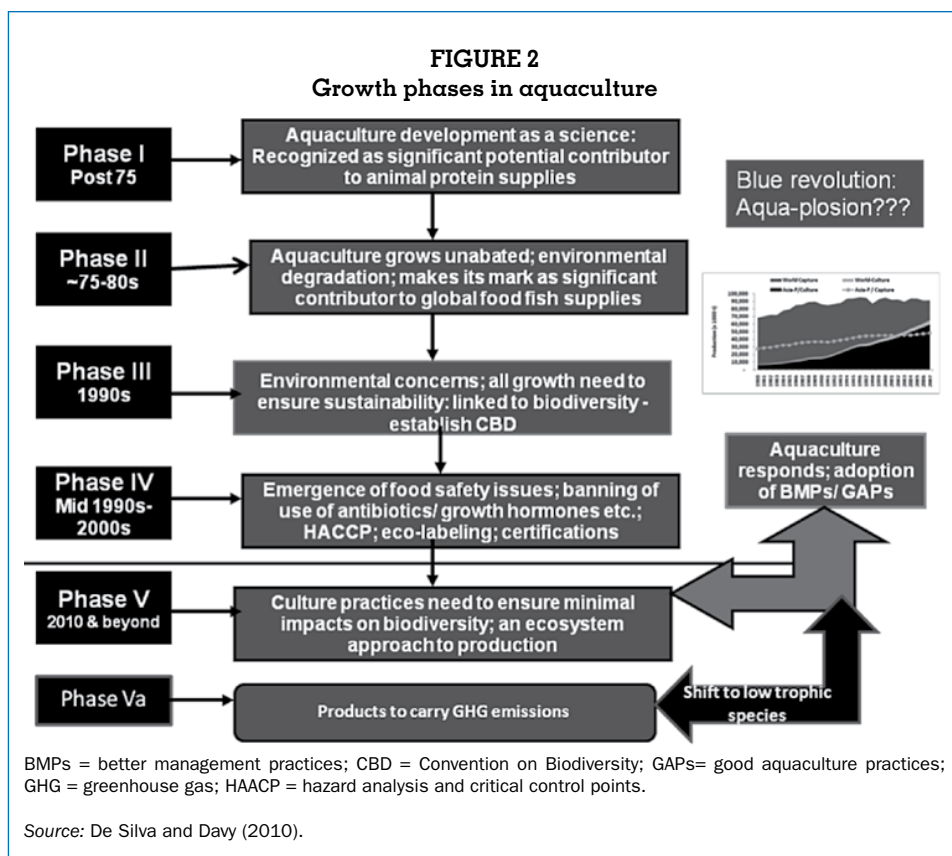


^a IP = intellectual propriety.

Source: WHO 06.111.

Change and aquaculture development phases

Our knowledge/communications thinking is evolving, at least in part, in concert with the overall past development of the aquaculture sector. Understanding knowledge trends seems fragmented or elusive, particularly in terms of



aquaculture's evolution and its extremely rapid growth in recent years. Some of us have attempted to look at these changes through development phases' thinking (De Silva and Davy, 2010) and the changing knowledge needs as seen in a broad brush fashion in Figure 2.

This initial examination has included some broad analysis of what is working (what we called success stories thinking; see De Silva and Davy, 2010) and in particular, examines success in small-scale aquaculture. This work provided a look back with some initial lessons learned related to the potential issues aquaculture may face as it moves into new future phases and in the context of perceived global changes and community aspirations over the next decade and beyond.

Clearly, the extremely rapid growth of aquaculture has a number of knowledge implications, often not yet attracting much detailed examination. For instance, aquaculture is attracting an increasing variety of new stakeholders as it grows rapidly (but we can find little data or examination of this trend). Linked to this change, aquaculture must also deal with a widening set of change processes and drivers of change; for instance related knowledge sharing related to the

Bangkok Declaration. Scale is another often controversial issue (for example, sustainability and small-scale operations vs large industrial ones) and level concerns (local to national to global), and particularly the latter is becoming of greater importance in recent years, often involving a complex mix of marketing linked increasingly to governance and social organization concerns. Other questions include whether we have adequate paradigms for dealing with the management of knowledge around development, change and sustainability that adequately deal with scale and level differences. Perhaps we need to examine new modes of thinking about the development of aquaculture, such as complex adaptive systems thinking (see Resilience Alliance, www.resalliance.org/) and other conceptual frameworks as part of this process (see De Silva and Davy, 2010 for more background on this issue).

The case-based approach to analyze knowledge management

Our panel reviewed a variety of knowledge and communications experiences through a selected examination of six cases that offer a broad global perspective. A series of lessons learned analyses follow, as part of our initial efforts to summarize knowledge and communications thinking related to these cases. The six case studies are:

- (i) catfish farming in Viet Nam,
- (ii) small-scale shrimp culture in India,
- (iii) marine cage farming in Turkey/Mediterranean Sea,
- (iv) salmon farming in Chile,
- (v) The European Aquaculture Technology and Innovation Platform, and
- (vi) the Network of Aquaculture Centres in Asia-Pacific (NACA) experiences on training, extension, knowledge and communications.

It is expected that such wider knowledge-sharing activities will intensify in the coming decade, guided by the goals set out in the Bangkok Declaration and hopefully further refined and improved at this conference. The specific case summaries are described below.

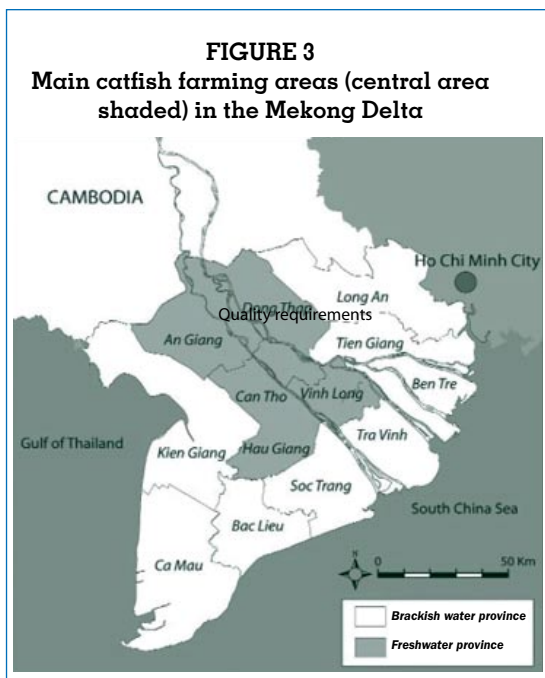
CASE STUDY 1

Striped catfish aquaculture in the Mekong Delta, Viet Nam: a knowledge-based development⁵

Background

The Mekong Delta in the southern part of Viet Nam is the main catfish farming area (Figure 3). The striped catfish (or “tra” catfish) is a single species of the genus *Pangasianodon* (i.e. *P. hypophthalmus*) that occurs in the lower Mekong basin waters of Viet Nam, Cambodia Lao PDR and Thailand. The fish

⁵ Prepared by N.T. Phuong, F.B. Davy, B. Ingram and S. De Silva.



has been farmed in the Mekong Delta for decades, as a home backyard development, primarily providing food fish needs of rural households. In the early phases of striped catfish culture, the seed stock was wild-caught from Cambodian and Vietnamese waters, particularly in the confluence region of the Mekong, Ba Sac and Tonle Sap rivers. The commercial culture in cages, pens and ponds commenced with the development of artificial mass seed production in 2000 (Tuan *et al.*, 2003). The pond culture system quickly expanded more rapidly than either pens or cages, and its production share now accounts for over 98 percent

of the total catfish production (Phuong and Oanh, 2009). The unprecedented development of catfish aquaculture in the Mekong Delta has been built on the outcomes of research and technology transfer during the last decade.

Salient points

Development and transfer of seed production technologies: a driving factor from research

The development of seed production technology was a key driving factor in the success of striped catfish farming in Viet Nam. Research on artificial propagation of pangasiid catfish first commenced in 1978 on striped catfish.⁶ The first fingerlings were produced in 1979–1980, independently at the Long Dinh Vocational School, Nong Lam University and Can Tho University, but the results were not sufficiently reliable for mass seed production until 1995 (Tuan *et al.*, 2003). However, the period of 1978–1980 can be considered the starting point for research on induced spawning of striped catfish. Research re-commenced in 1995 under a European Union (EU) funded project, which was led by Can Tho University. Partners of this project included the French Agricultural Research Centre for International Development (CIRAD), the Research Institute for Development (IRD) (France), Can Tho University (CTU) and An Giang Fisheries Import-Export Joint Stock Company (AGIFISH) (Viet Nam). The primary achievement of the induced spawning techniques was in 1996,

⁶ Presentation by T.T. Xuan on “Some biological characteristics and artificial reproduction of river catfish (*Pangasius micronemus* Bleeker) in the South Vietnam” presented at the International Workshop on the Biological Bases for Aquaculture of Siluriformes, May 24–27/1994, Montpellier, France.

and the full achievement was established in 2000 (Cacot, 1999; Cacot *et al.*, 2002). The induced spawning technique for striped catfish was therefore fully developed from scientific research. The transfer of techniques happened almost immediately after the success and involved different approaches. The initial stage started in 1999, when the techniques were transferred to a few advanced private hatcheries with a hands-on approach. The owners of these hatcheries were already experienced in fish hatchery operations and management and therefore, they were able to adapt the techniques rapidly and successfully. The staff of Can Tho University involved in the research played a key role in this stage of the knowledge dissemination. The second key stage of technology transfer was from 2000 to 2002, when the techniques were transferred by short-course training (included theory and hands-on practice) for large numbers of farmers who were hatchery owners or technicians, and non-hatchery operators. Can Tho University and the Research Institute for Aquaculture No. 2 (RIA-2) were two key stakeholders at this phase. A number of current and newly established hatcheries were involved in tra catfish larval production that resulted in significant increases of larval production. In the third period, the techniques were primarily transferred from farmer to farmer and from provincial state-run hatcheries to farmers, whereas the role of institutions (such as CTU and RIA No. 2) became less prominent. In recent years, newly established large-scale hatcheries tend to receive a full package of techniques including hatchery design, operation and transfer from either research and or educational institutions.

The approach to technology transfer for hatchery production of striped catfish varies depending on the development stage of the sector. Stakeholders may require different ways of receiving techniques depending on their target objectives. Experienced farmers require consultation, while other farmers require formal training or even full technology packages.

Development and improvement of grow-out technology: a research-based success

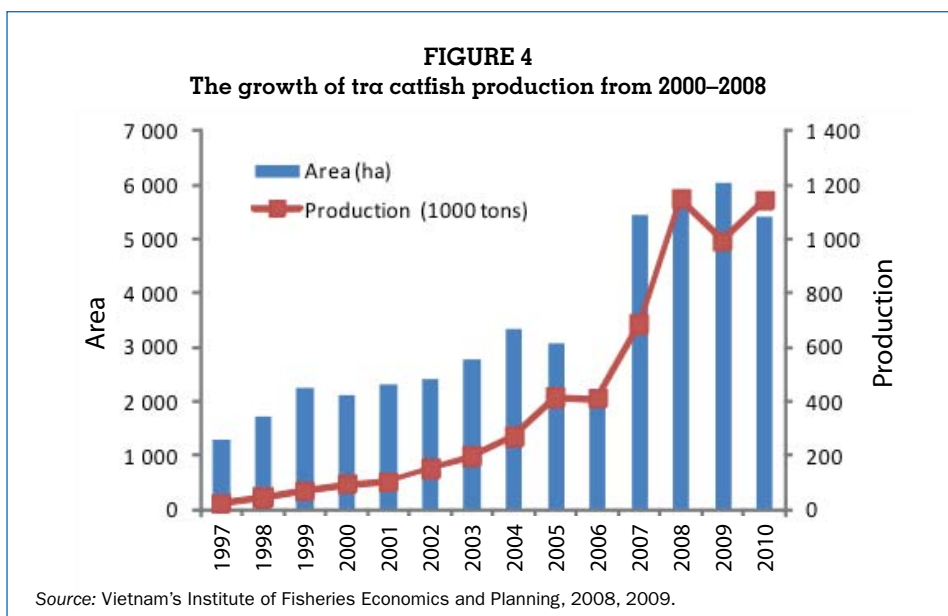
Three main production systems for tra catfish have developed in the Mekong Delta, namely pond, cage and pen culture. The development of these production systems has changed mainly in response to technical developments and economic efficiency. In fact, the catfish production in the Mekong Delta, Viet Nam had commenced with Mekong River catfish (*Pangasius bocourti*) (locally referred to as “basa”) in cages in the early 1960s and striped catfish (locally referred to as “tra”) began in family/backyard ponds in the 1950s using wild-caught fingerlings (see Table 1).

The cage culture of basa catfish was initiated by expatriate Vietnamese in Cambodia who came back to Viet Nam, while pond culture of tra catfish was developed by local farmers. The reduction of fingerling supply of basa catfish and the success of induced spawning of tra catfish are considered two key drivers for the development of tra catfish farming in the Mekong Delta, Viet Nam.

TABLE 1
The timeline of tra catfish seed-production development

Period	Important Events
Prior to 2000	– Wild larval collection and nursery rearing started in the 1940s was a key activity of a number of farmers since 1954. This activity provided seed stocks for home pond culture until the beginning of 2000 when hatchery-reared seed became available.
Late 1970/90s: initial years of research	– Research on induced spawning was initiated in 1979. The first fingerlings were initially produced in 1979 by a joint effort of Long Dinh Vocational School, Nong Lam University and Can Tho University. These initial successes could not be repeated, and research activities were scaled down until solved in 1995. The period 1978 to 1980 could be considered as the starting point of research on induced spawning of striped catfish.
1995-1998: successful years	– Research was re-initiated in 1995 under the European Commission, involving the French Agricultural Research Centre (CIRAD), the Research Institute for Development (IRD) France, Can Tho University and An Giang Fisheries Import Export Joint Stock Company (AGIFISH). The induced spawning technique was successful in 1995 with complete success in the following years.
2004-present: rapid growth years	<ul style="list-style-type: none"> – Striped catfish hatcheries, especially large-scale hatcheries of private companies, were rapidly established. Transfer and consultation on the hatchery operation technique was mainly by CTU and Research Institute for Aquaculture (RIA) No. 2. – Genetic improvement research was initiated in 2002, and the first batch of improved broodstock was obtained and introduced to some selected hatcheries. – The seed production technique for striped catfish can now be done in most freshwater hatcheries in the Mekong Delta and has also been introduced to other parts of Viet Nam. – Consolidation of the sector through the development and adoption of better management practices (BMPs) and a cluster approach to adoption is taking place rapidly. This will enable small-scale farmers to remain economically viable, ensure the sustainability of the sector and most of all, ensure market access.

The intensive production of tra catfish has involved three different systems (e.g. cages, pens and ponds) during the gradual development of culture technology. The first intensive pond culture of tra catfish was conducted in 1981–1982 by a farmer in Can Tho City using wild collected fingerlings. The stocking was tested at 10–12 individuals/m², and the farm yield was 90–120 tonnes/ha/crop. However, the success of this test case attracted few other farmers to begin tra catfish pond culture in the following years. The high ratio of harvested fish with yellow flesh, which is not exportable, has been a key disadvantage of tra catfish production in ponds. During 1996–1999, many research activities were conducted that focussed on the improvement of feed (e.g. use of commercial pellets instead of home-made feeds) and increase of water exchange in order to improve flesh quality. These studies have led to significant improvements in culture techniques, flesh colour and yield. The success of tra catfish culture in ponds together with the availability of hatchery-reared fingerlings has also stimulated the development of tra catfish production in cages and pens. Pen culture involves use of a fixed enclosure built on the river bank using metal or bamboo. The cage culture of tra catfish commenced in 2000, due to a reduction of basa catfish wild-collected fingerlings and the high flesh quality (white colour). However, by 2004 these production systems were significantly reduced and became unimportant in tra catfish production. The production from cage and



pen systems has accounted for less than 2 percent of the total tra catfish production during the last few years. The decline of these culture practices was primarily due to the slower growth rates, higher mortality and frequent disease outbreaks that led to reduced economic efficiency compared to pond practices (Phuong *et al.*, 2004).

Tra catfish pond culture continues to develop and has now become an aquaculture activity of immense economic importance. In 2008, there was over 5 300 ha of ponds with a production of 1.2 million tonnes.⁷ The technique for this culture system has passed through different developmental stages which have involved innovations and knowledge from both the farmers and the research sector. Generally, the farmers initially innovated many details of the technical package, while the researchers have contributed supplementary details and assisted in solving problems that arose during the period from 1996 to 2000. However, the current intensification in pond production has been significantly improved during the last decade, based on the research activities of universities and research institutes such as CTU and RIA-2. These research achievements have focussed on key technical issues such as stocking density, pond water management, health management, feed and feeding, drugs and chemical use. In 1981–1982, the first farmer in Can Tho City initiated intensive culture of catfish in a few small ponds with low stocking density of 10–12 fish/m² and productivity of 90–120 tonnes/ha. By 2008, intensive pond production had expanded to 5 300 ha and the stocking density has increased remarkably up to 52.8 fish/m² (Phuong and Oanh, 2010) or 48 fish/m² (Phan *et al.* 2009).

⁷ Source: Presentation by N.H. Dung on “Vietnam pangasius and world markets” presented at the International Workshop on Pangasius Catfish. Can Tho University, 5–6 December 2008.

The farm yields ranged from 70.0 to 850 tonnes/ha (mean of 406 tonnes/ha) (Phan *et al.*, 2009); about 70 percent of the farmers had shifted from home-made feed to commercial pellets.

The move to more sustainable production of tra catfish in ponds is an important issue for the future of the sector. There have been many standards and practices introduced to farmers at different scales. The first standard, namely SQF-1000 (safe quality food), was introduced by two provincial departments of agriculture and rural development in 2003. This activity has been considered as a starting point for other standards or practices introduced in later years. These start-up activities were conducted by demonstration farms using short-course training for large numbers of farmers. The first organic farming of tra catfish in ponds and pens was introduced to selected farmers by the Binca Seafood GmbH Company⁸ in 2004. AquaGAP⁹ and GlobalGAP¹⁰ practices in tra catfish pond systems have also been tested at Vinh Hoan Corporation, which produced high-quality fish for specific markets such as the United States of America. A new BMP (Better Management Practices) project has been implemented since 2008 by a partnership that includes CTU, RIA-2, Fisheries Victoria, Australia and the Network of Aquaculture Centres in Asia-Pacific (NACA). The project aims to develop BMP standards for wider application in tra catfish production, including hatchery, nursery and pond grow out, and is attempting to develop sustainable production practices as well as cluster-shared learning approaches among farmers, especially small-scale farmers.

The rapid growth of intensive tra catfish farming has undoubtedly resulted from the technical dissemination conducted by a wide range of parties including universities, research institutes, national and local fisheries and aquaculture extension agencies, trading companies and producers. However, the most effective approach to technical dissemination is still difficult to define, because it has been an integrated process. The technical transfer in the initial phase was done in demonstration farms, conducted by universities, research institutes and local fisheries agencies under local and internationally supported projects. The techniques were disseminated through various channels during the rapid growth phase (2000–2004), such as training courses for farmers, both farmer-managed and researcher-guided demonstration farms, on-farm consultations and regular live programmes on television. Universities, research institutes, local fisheries agencies, companies and advanced farmers have been actively involved in these processes. The transfer of technology has not been as important as in the previous period because farmers are now more knowledgeable.

⁸ Binca Seafood GmbH is a German importer of seafood, primarily deep-frozen, from Asia to European markets.

⁹ A certification programme for good aquaculture practices (www.aquagap.net).

¹⁰ A private sector body that sets voluntary standards for the certification of production processes of agricultural (including aquaculture) products around the globe (www.globalgap.org/cms/front_content.php?idcat=9).

TABLE 2
Timeline of tra catfish grow-out development: documentation of key knowledge change events

Period	Important Events
1940–1950	Culture in small family ponds using wild-collected fingerlings commenced in An Giang and Dong Thap provinces, which are up-stream of the Mekong River Delta in Viet Nam.
1981–1982: trials of pond culture	First trials of tra catfish intensive culture in small ponds conducted by a farmer in Can Tho City using wild-caught fingerlings.
1996–1999: expansion of pond culture and trials of cage culture	Intensive culture in ponds expanded gradually to other provinces. First trials in cages (replacement of basa catfish) and pens were conducted as well. Both production systems used wild and hatchery-reared fingerlings.
2000–2004: rapid expansion of cage and pond culture	Intensive culture in cages and ponds expanded rapidly. Hatchery-reared fingerlings met the demand for stocking. Productivity was significantly improved. Farmers gradually shifted from homemade to commercial feeds.
2005–present: high increase of productivity	Collapse of tra catfish cage and pen culture occurred. There were significant improvements of pond culture techniques and remarkable increases in productivity. Introduction of sustainable production standards such as SQF-1000, AquaGAP, GlobalGAP and BMPs.

Key lessons and the way forward

Tra catfish farming industry in the Mekong River Delta, Viet Nam has had an unprecedented growth within a decade, perhaps never witnessed before in the global aquaculture sector. This remarkable growth has resulted from scientific achievements as well as farmers' knowledge, perseverance and resilience. The technical dissemination has been implemented by various approaches, contributed to by a wide range of stakeholders such as universities, research institutes, local fishery agencies, companies and advanced farmers. The question now is whether a different KM is needed to consolidate the sector and make it sustainable in time

CASE STUDY 2

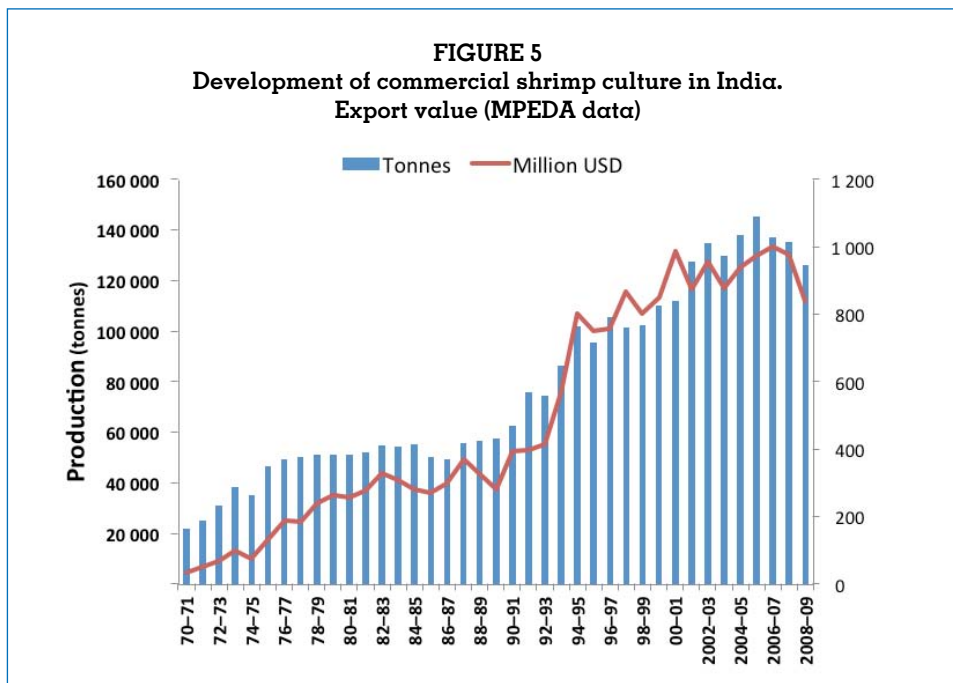
Sustainable shrimp aquaculture production through cluster farming approach – The Indian story¹¹

Background

The economic benefits of shrimp aquaculture, in particular foreign exchange earnings and provision of employment, are highly important to the Indian economy. Figure 5 depicts the impact of the advent of commercial shrimp aquaculture in the country. The potential area available in the coastal region of the country for shrimp farming is estimated to be about 1.2 million ha. Shrimp farming provides direct employment to about 0.3 million people and ancillary units provide employment to 0.6–0.7 million people (Coastal Aquaculture Authority www.caa.gov.in). Presently, an area of about 157 000 ha is farmed, with an average production of about 100 000 tonnes of shrimp per year over

¹¹ Prepared by V. Bhat and N. R. Umesh.

the last five years. Farmed shrimp production reached 143 170 tonnes from a farming area of 140 000 ha, and another 42 820 tonnes of scampi (giant freshwater prawn, *Macrobrachium rosenbergii*) were produced from 43,000 ha during 2006–2007, generating about INR40 790 million in export sales, equivalent to USD0.8 billion (Marine Products Export Development Authority, MPEDA¹²). The average productivity has been estimated at 660 kg/ha/year. Cultured shrimp contribute about 50 per cent of the total shrimp exports from India. The technology adopted ranges from traditional, to improved traditional and extensive shrimp farming. About 91 per cent of the country's shrimp farmers have a holding of less than 2 ha, 6 per cent have between 2 and 5 ha, and the remaining 3 per cent have an area of 5 ha or above. Shrimp farms are operated using both leased out government/private lands and landowner-operated holdings. On average, each farmer spends about USD3 000 for one crop. In earlier times, a credit system functioned throughout the sector, operated and controlled primarily by intermediaries. Intermediaries also acted as input suppliers and providers of credit at each stage in the supply chain and were also involved in buying back the harvested shrimp. On average, farmers ended up paying a whopping 30 per cent interest on the loans from the intermediaries, which markedly affected the profitability of their operations. Returns from shrimp farming continue to be rewarding, benefiting small-scale farmers and coastal communities, as well as entrepreneurs engaged in seed production, farming operations or ancillary activities. Sustainable utilization of available areas and infrastructure can lead to the development of under-exploited resources, with



¹² www.mpeda.com

the potential of generating a large number of jobs and enormous social and economic benefits to the coastal regions of the country, thus improving the quality of life in rural areas.

From 2000 to 2006, the MPEDA carried out a collaborative project with the technical assistance of the Network of Aquaculture Centres in Asia-Pacific (NACA). A number of science-based farm-level managerial interventions were identified that could be relatively easily adopted by the farmers for prevention of white spot disease (WSD) in their ponds and for increasing production, productivity and returns. These interventions were developed into better management practices (BMPs) to be adopted even by small and marginal farmers. The effectiveness of the BMPs was demonstrated in a series of village-level demonstration programmes carried out by the MPEDA-NACA project. Initially, the small farmers were encouraged to come together into informal groups called “aqua clubs”.

In order to promote sector-wide adoption of BMPs, in 2007 MPEDA set up an outreach organization, the National Centre for Sustainable Aquaculture (NaCSA) under its umbrella. The primary objective of NaCSA is to support development of sustainable aquaculture in India through facilitation and empowering the marginalized and poorest of the poor in the aquaculture sector, besides disseminating technologies and information on better practices, sustainable and judicious utilization of the resources, use of science in day to day activities, marketing of the produce, etc.

NaCSA is building capacity at the grass-roots level among the primary producers through disseminating technologies and information on BMPs, and the sustainable and judicious utilization of the resources to produce safe shrimp and a sustainable industry. The core technology around which the BMPs developed was health management, the state of an animal’s health being the expression of several factors including genetics, nutrition and the environment. The BMPs also embodied specific and broad practices that provided the conditions to maintain the well being of the cultured stock. The specific approaches included preventive or curative measures without resorting to (or if possible, with little use of) chemicals; maintenance of water quality and substrate; and proper nutrition and feeding. The broad practices included reducing or coping with the risks of pathogens being introduced into the farms through such practices as synchronized water intake and discharge, simultaneous cropping, observation of early warning signs and notification of neighbours of disease onset, learning from each other, assuring product quality and safety and, overall, acting collectively in their own interest.

In effect, the BMPs embodied the principles of sustainable farming plus a good dose of market-driven thinking. The key to moving these concepts into sustained practices was getting farmers involved and collaborating. Thus, the process

commenced with the organization of small-scale farmers into clusters or aqua clubs, particularly grouping farmers in a given area around shared resources and common problems such as the use of a common water supply channel. Such clusters/aqua-clubs subsequently became aquaculture societies with a legal status. The impacts and outcomes of this work of NaCSA included improved shrimp yields, reduced impact on the environment, improved product quality and better relations among players in the market chain. The organization of small-scale farmers into groups and then into more formal societies facilitated the adoption and implementation of BMPs, providing benefits to the farmers, the environment and society. Overall, there were increased shared social and moral norms, which helped transcend narrow self-interests. Interestingly, this process also led to the emergence of farmer leaders in each group who were otherwise obscure until they organized as a group.

Salient points

Farmer society formation and management for knowledge sharing and learning

The farmer groups now established by NaCSA are known officially as Aquaculture Farmers Welfare Societies. A farmer society constitutes a group of aquaculture farmers in a specific locality or farming cluster who implement and manage their aquaculture activities using a participatory and “bottom-up” approach in order to achieve three main objectives; viz. reducing disease risks, reducing costs of production and meeting market demands through sustainable farming. The farmer societies are set up according to a model established by government, registered under the Registration of Societies Act of the respective state governments. These societies are required to submit annual reports and audited statements of accounts to the government and ensure a democratic and transparent management. Each society consists of members comprising from 20–75 farmers who have registered their farms with the government. Membership is voluntary. Each society has a clear organizational structure, including a president and a democratically elected board and has weekly general meetings where farmers can share information and collective decisions can be made. The societies so registered with the Registrar of Societies and voluntarily acceding to adopt a set of code of practices for sustainable shrimp aquaculture are encouraged to register with MPEDA. This entity introduced a scheme for registration of societies for adoption of codes of practices for sustainable aquaculture in the year 2006–07. Under this scheme, MPEDA provides incentives for managing common facilities that would help the farmers to produce quality and safe shrimp and demonstrate eco-friendly sustainable shrimp culture.

Society activities include the collective preparation of a crop calendar two months before stocking to ensure all society and cluster farmers stock their ponds within a two-week period of each other. The maximum stocking density for each society is decided, and society farmers agree not to use any

antibiotics or chemicals. High-quality seed is purchased by the societies using a contract hatchery system. Societies agree to follow shared practices such as synchronized water intake and discharge, simultaneous cropping, observing early warning signs of disease onset, learning from each other, assuring product quality and safety and, overall, agree to act collectively. Each society has standard operating procedures (SOPs), and internal control systems (ICS) are being established in societies to ensure compliance with minimum standards by all society members.

Key knowledge-linked BMPs developed and implemented in the project

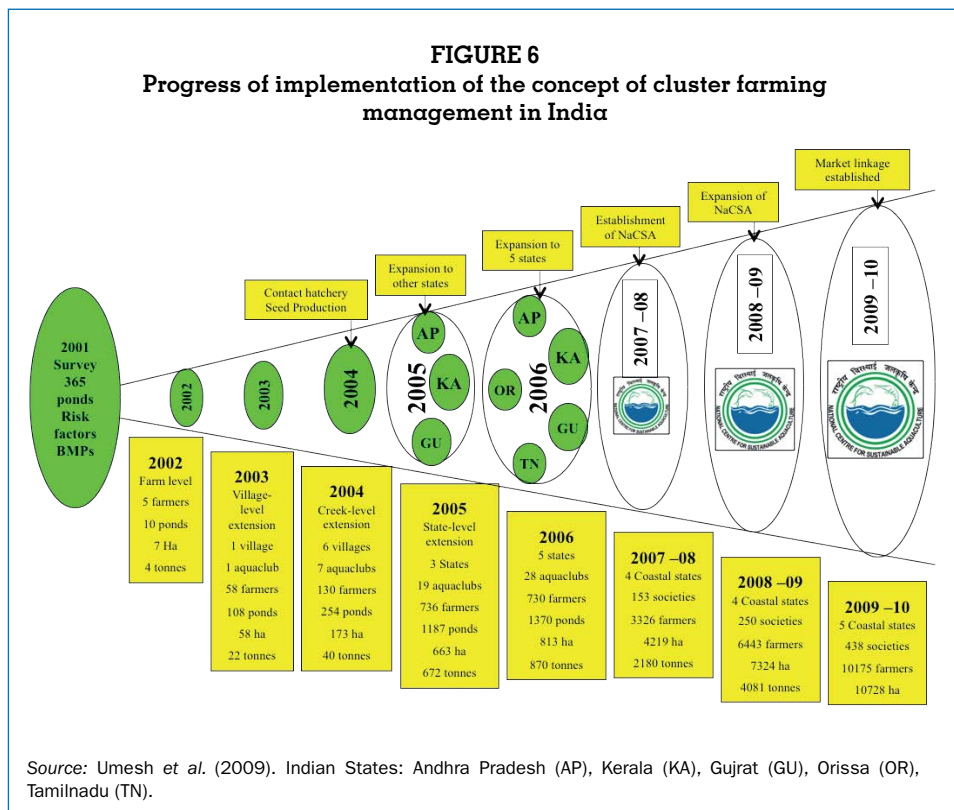
These include:

- *Good pond/water preparation*: The soil should be checked for the presence of a black layer, and it should be removed from the pond. Water should be screened at the water intake point to avoid entry of virus-carrying fish and crustaceans or predators/competitors of shrimp. Water depth of at least 80 cm should be maintained in the pond.
- *Good-quality seed selection*: Quality seed is best purchased through the contract hatchery seed procurement system where seed is obtained via a group purchase.
- *Water quality management*: Basic water quality parameters such as dissolved oxygen, pH and alkalinity must be maintained at optimum levels. Water exchange is only when necessary and during critical periods.
- *Feed management*: This includes efficient use of quality feed, demand feeding using check trays, and feeding across the pond using a boat or floating device. Feed conversion ratio (FCR) must be kept below 1:1.5.
- *Pond bottom monitoring*: The pond bottom soil should be monitored on weekly basis for black soil, benthic algae and bad smell, especially at the feeding area or trench, and corrective actions should be taken.
- *Health monitoring and biosecurity arrangements*: No draining or abandoning of disease-affected stocks. Farmer groups are encouraged to discuss common actions that can be taken during disease outbreaks to avoid spreading of disease from one farm to another. Farmers are encouraged to provide bird scare devices.
- *Food safety*: Use of any harmful/banned chemicals like pesticides, antibiotics and pharmacologically active substances should be avoided.
- *Better harvest and postharvest practices*: These include quick harvesting, chill-killing of harvested shrimp and quick transport to the processing plant.
- *Record maintenance/traceability*: A hatchery/pond management record book should be maintained by hatcheries and farms to identify problems in the tank, pond and environment and to rectify these at the earliest time during the production cycle. This is also required for traceability purposes.
- *Environmental awareness*: Improved environmental awareness about mangroves, pollution and waste management is promoted among farmers.

The societies are annually audited by MPEDA for the implementation of BMPs. Societies which fail to implement BMPs would lose registration. Each farmer society has one coordinator selected from among the society members or from the community by society farmers. The society coordinator is trained in society management, BMPs and extension techniques by NaCSA, and is responsible for implementing BMPs in societies and acting as the link between society farmers and NaCSA. Each of the NaCSA field managers coordinates and manages the activities of ten such societies. MPEDA's society scheme provides 50 percent financial assistance for farmers to employ a society coordinator for the initial two years.

Progress made to date

NaCSA has made significant progress in organizing and registering aquaculture societies, with the number of farmers adopting the cluster management approach growing exponentially from five farmers in 2002 (covering 7 ha of area in one state) to 10 175 farmers in 438 societies (covering 10 728 ha) to date in five coastal states. The majority of these societies are in the State of Andhra Pradesh, which produces half of the farmed shrimp in India. Figure 6 provides an illustration of the evolution and progress made in the implementation of the cluster farming concept in India.



Benefits of organizing aquaculture societies

Empowering small-scale farmers: Organized farmer groups (societies) are one of the key mechanisms for supporting farmer empowerment. They have the potential for cooperative action, which can change the position of the farmer in relation to the opportunity structures and thereby influence the business environment of the farming community. Moreover, small-scale farmers, through organization, can gain an advantage of economies of scale in accessing services and markets, which are otherwise limited to large commercial farmers. The small-scale shrimp farmer groups of India are in a better position today to gain these benefits compared to the situation when they were unorganized. Selected benefits of organizing small-scale farmers include:

- farmers organizations receive legal status;
- improved technical and financial sustainability;
- improved knowledge exchange and sharing of experiences;
- middlemen/agents are eliminated at all levels;
- societies provide a workable model for small-scale farmers to meet market requirements;
- increasing stakeholder interaction and involvement;
- revival of livelihood;
- increased awareness and social responsibility; and
- self-propagating nature of the model.

Some of these are reviewed below.

Improved technical and financial sustainability: The improved technical practices included reducing or coping with the risks of pathogens being introduced into the farms through synchronized water intake and discharge, simultaneous cropping, putting up and observing early warning signs of disease onset, learning from each other, assuring product quality and food safety and, overall, acting collectively. Implementation of simple, science-based farm practices and adoption of cluster farming promoted cooperation among farmers and significantly reduced disease risks in society farms. The prevalence of shrimp disease in the society farms decreased from 82 percent in 2003 to <20 percent in 2009, while in non-society ponds/farms the reduction in disease prevalence was very low during the same period.

Similarly, the society farmers achieved higher profits through increased production, increased size of shrimp, improvement in survival, reduction in disease prevalence, reduced use of chemicals and no use of antibiotics, as well as sharing of many expenses – society farmers share the common expenses related to deepening of canals, seed testing, transportation of inputs, laboratory costs, electricity, etc. Societies also offer better opportunity for common infrastructure development.

Improved knowledge exchange and sharing of experiences: Exchange of information, experience and ideas among farmers was the key for success of societies. Each society typically included a few farmers who were proactive and who quickly grasped the importance of implementation of BMPs. These were the farmers who in turn talked to and convinced other farmers and generally helped the NaCSA team to spread the awareness about BMPs. Farmers in societies make decisions collectively; the functioning of societies is very transparent in a democratic system. There is regular information sharing among farmers during weekly meetings, including that concerning the purchase of quality inputs and selling of the farm produce.

Middlemen/agents are eliminated at all levels: Aquaculture societies are successful in eliminating middlemen in the value chain. Previously middlemen were involved at three stages: in the purchase of seed, in provision of credit and in the purchase of shrimp.

Societies – an ideal model for small-scale farmers to meet market requirements

Over the years, the approach to quality management has assumed greater significance and importance in the seafood sector worldwide, both in production and supply chains. New trends are emerging in production and marketing such as traceability, ecolabelling and certification. For farmers and producers in developing countries, supplying goods for national and international markets can present a life-changing opportunity as well as a challenge. Retailer demand is there – especially for products with ethical and green credentials. The difficulty lies in meeting those retailer needs and identifying the right products at the right time. Developing-country producers often lack the skills to deal with the high demands of export markets, as well as access to capital and business expertise. These factors collectively present a formidable barrier to entry into more sophisticated markets. At the other end of the supply chain, retailers often lack the ability to be able to reliably source quality products that are required for consumers.

Opportunity for fair-trade certification

Of late, farmers are under distress as farm-gate shrimp prices fluctuate based on supply and demand. Those small farmers who are entirely dependent on shrimp farming place their livelihoods at stake every time they stock their pond. A mechanism that would provide access to good markets and a fair price would allow small farmers to maintain their activity and ensure livelihoods. There is need for a fair trade labelling of society produce so that society farmers can get a more stable price that covers at least production and living costs, which is an essential requirement for farmers to provide themselves and their families with a decent standard of living. NaCSA is also exploring opportunities to work with FLO-CERT, the fair trade certification body.

Traceability

A record of traceability is another common requirement from buyers with which it is often hard for small-scale farmers to comply. However, NaCSA has trained society coordinators and farmers in record keeping and supplies them with pond-record books. This enables society farmers to keep full records on general management, key parameters, purchasing and distribution. Satellite maps are also used to trace the pond production, making it much easier for society farmers to meet traceability requirements of buyers. Overall, NaCSA with the help of various experts is developing a comprehensive traceability system linking all the stakeholders involved in the value chain.

Knowledge sharing lessons learned

TABLE 3

Summary of positive knowledge impacts (what worked, is working)

Risks	Positive impacts	Remarks
Disease	– Reduced disease incidence	– 27 percent decrease of disease prevalence in BMP ponds compared to non-BMP ponds
Food safety	– Reduced chemical & no antibiotic use	– Random giant tiger prawn (<i>Penaeus monodon</i>) samples from society ponds tested negative for presence of antibiotics in over 90% of cases – Complete traceability of the product
Market access	– Increased opportunity for market access	– Efficiently managed small-farmer societies provide similar advantage of integrated larger units – Traceable shrimp from societies (traceability from broodstock to pond level)
Financial	– Improved profits – Opportunity for bank credit access	– By reducing the cost of production, profits have been increased. Non-BMP ponds got INR39 (USD0.8) for every INR1 000 (USD20) spent, whereas BMP ponds got INR128 (USD2.6) for the same investment
Social	– Democratic & transparent societies: <ul style="list-style-type: none"> ▪ sharing of costs ▪ increased communication ▪ harmony among farmers 	– Democratically organized farmer groups – Regular information sharing among farmers – Cooperation in selecting/testing & buying quality seed & other inputs – Farmer field days help farmers to share their successful experiences – Each society has a minimum of ten meetings during the crop period
Environmental	– Lower stocking densities – Reduced pollution – Increasing awareness on environment	– The low stocking density of shrimp ponds in societies (2 to 6 shrimp per m ²) is far below the level when compared to other countries – Two societies have adopted organic aquaculture practices – Abandoned shrimp ponds being revived

Key lessons and the way forward

Effectively engaging with the thousands of aquaculture producers in India and helping them to develop farm-level plans for sustainable development is not an easy task and can only be achieved with the involvement and contribution of the many players involved in the supply chain, from producers to consumers. The exchange of information, experience and ideas among farmers was the key for the success of such societies; for example, sharing information on better

market access is essential to address many challenges faced by small-scale shrimp farmers. MPEDA/NaCSA are seeking to link societies directly to a preferred processor or exporter, cutting out the middleman. This type of vertical integration will ensure decreased transaction costs for farmers and processors/exporters, allowing farmers to receive a better price for their produce and to coordinate harvest and postharvest practices to improve the overall quality of the shrimp and maintain traceability.

A critical on-going priority for societies is access to credit and reducing their current interest burden on loans from moneylenders and other private sources. Well-establishing links between societies and output markets are vital to the success of societies. Developing partnerships with local processors provides a good opportunity for societies to access better markets as well as bank credit (agreements with processors provide societies with a market guarantee, which is a major concern of banks). NaCSA continues to work towards bringing processors and farmers together for better market access. The implementation of BMPs by farmers is providing them with an opportunity to create a niche for such products in the global market, which will help in sustaining small farmers' livelihoods in India. Clearly, farmers were able to make use of the pond management and market and related new knowledge sources, using this to change their behaviours towards more sustainable culture systems that both improved the environment and their profitability.

CASE STUDY 3

The Chilean salmon industry: a brief review of its history and the role of knowledge and communications in its development¹³

Background

Chile has had one of the fastest growth rates of the aquaculture sector worldwide with an average annual increase of 18 percent. In 2007, aquaculture exports reached USD2.4 billion with large social and economic impacts, particularly in the southern region where salmon and mussels are being cultured. The Chilean salmon industry only started in the early 1980s and in a very short time became the second-largest producer worldwide of farmed salmon and the largest producer of farmed sea trout. Production presently includes coho (*Oncorhynchus kisutch*), Atlantic (*Salmo salar*) and chinook (*O. tshawytscha*) salmon as well as trout (*O. Mykiss*), and this industry generates very important impacts in the local communities in the southern regions of Chile, specially in Puerto Montt and the island of Chiloe.

The development of supporting knowledge systems through research and technical expertise has also been critically important in this sector's development.

¹³ Prepared by R. Infante and D. Soto.

For instance, once salmon farming became a booming activity, a variety of universities opened new programmes related to aquaculture, at both the technical and engineering level¹⁴, and specific research expertise has developed both locally in the south and in the capital region.

Salient points

The role of institutions and public–private partnerships in transferring and producing new knowledge and technologies

Several new institutions and active partnerships have developed and/or promoted the development of research and technology, often as part of research-business partnerships. Key institutions include Fundación Chile, Corporación de Fomento de la Producción (CORFO) and the Instituto Tecnológico del Salmón (INTESAL, the salmon technological institute created by the salmon farmers association). The government also played an important role through the National Fisheries Council, which supports the Fondo de Investigación Pesquera (FIP, the Fisheries Research Fund). This institution promoted a thorough review of investments in aquaculture research in Chile and their impacts during the past decade (Bravo, 2007). Between 1996 and 2004, Chile invested 0.56 percent of its gross domestic product (GDP) in science and technology in general, while the investment in “aquaculture focussed” research and development (R&D) reached 3.89 percent. Although more emphasis was given to this growing revenue-producing sector, the study also concluded that the investment in research in Chile has not been commensurate with the increase in salmon and mussel production (the most important export commodities). Thus, a large portion of knowledge and technology advances were still being imported from other countries or generated locally at the farm level. On the other hand, a significant proportion of the research investment has gone to the culture of seaweeds and crustaceans; however, the latter has not had an apparent impact on the production of these species. Another important conclusion of the study (drawn from a poll within stakeholders) was that the research in aquaculture was not adequately related to the needs of the sector, particularly the needs of the farmers.

Historically, salmon farming in Chile developed in a couple of decades from small family-owned, almost artisanal production units into vertically integrated large companies, some of which are owned by foreign companies. In fact, foreign firms control about 35 percent of production in Chile, with Norway being the main source of such investment. Most companies generate some of the needed knowledge at the local farm and company level (e.g. 60 percent have their own research programmes; Vergara, 2005). There is no definitive documentation, but it appears that at least part of the initial success of different salmon farms has been achieved through a trial and error knowledge management approach which

¹⁴ Universidad de Los Lagos, Universidad Austral, Universidad Santo Tomás and Universidad San Sebastián are local universities (in the “Lakes region”) that currently provide undergraduate and graduate education related to aquaculture.

has often then spread across the whole sector. Other forms of national and local innovation most often driven by the salmon-farming companies in Chile included the increasing production of eggs within the country, genetic improvement programmes and improvements in feed formulation (Parada, 2010). It is worth mentioning that there were key institutions promoting the development of the sector and the transference of technology. For example, Fundación Chile helped develop the salmon industry by applying an innovative technology transfer system that involved the start up and operation of new companies with state-of-the-art technology in high-risk business projects that required intensive investments in research and development. Once these companies became operational and profitable, they were sold off to the private sector. With this approach, Fundación Chile created the Salmones Antártica company in the 1980s, and in later years, other related companies such as Salmones Huillinco, Salmotec and Finamar (Perlman and Juárez-Rubio, 2010).

Recently, however, the industry suffered a major crisis despite what was thought to be a solid knowledge base including relevant knowledge on environmental issues, biosecurity requirements and disease risks. This apparently well-prepared industry suffered major losses associated with its principal species, Atlantic salmon, to the infectious salmon anemia virus (ISAV) (Falk *et al.*, 1997), leading to losses of over USD1 billion worth of exports and serious job losses, placing the whole economy of the region in a difficult situation. Therefore, the question remains, were there knowledge/communications gaps in the prevention, development and spread of this disease?

A critical series of knowledge management problems

Back in the 1990s, a new type of bacteria, *Rickettsia*, was discovered in the salmon grown in Chile. The presence of this organism was associated with non-specific mortalities initially referred to as due to a UA (unknown agent), later named as salmon rickettsial syndrome (SRS). This agent mainly causes a complete depletion of the immune system of the fish, and all related salmon species are susceptible.

The sea louse *Caligus rogercresseyi* is an ectoparasite that affects salmonids and also lives on other wild fish in the area. This parasite debilitates the fish by eroding the skin and thus eliminating the natural barrier against fungi and other pathogens. Populations of these parasites can be controlled through better management and the use of various approved drugs. However, the drug approval process is very lengthy, leaving farmers for years with only one approved drug for use throughout these severe outbreaks (Bravo, Sevatdal and Horseberg, 2008).

ISAV had been present in all salmon-producing countries worldwide except apparently Chile until June 2007, when the first case was reported, and since then many other cases appeared, leading to the crises described above. This

sanitary problem is complex and illustrates the knowledge and management challenges that go beyond ISA and the presence of other pathogens. The wider production system and related ecosystem factors such as the amount of production on a site, the quality of the smolts and the proximity of other farm sites in the production areas are all aspects that have increased this fish health problem; a future scenario that many others may face. A deeper analysis of some of these aspects, their interactions and solutions might assist others in better understanding the evolution of this problem.

The research and knowledge development process in Chile

In Chile, in general, research and knowledge formation has not been a high priority; Bravo (2007) analyzed Chilean investment in R&D, showing that salmon farming has received about 20 percent of the funds invested in aquaculture R&D, from 1987–2005 approximately USD31 million. However, this investment in research was not commensurate with the export value of the industry (USD2 billion in 2007). This amount represents a much lower relative investment compared to Norway were, for example investments in one biennium (1988-1990) amounted to near USD60 million (Asche, Guttormsen, and Tveterås, 1999). A similar conclusion is revealed by a global analysis of impacts of Atlantic salmon escapes (Thorstad *et al.*, 2008) when referring to the sources and funding of available information. Another important element is that most research has been funded by the government; the private sector has made comparatively smaller contributions, although it is slowly increasing.

INTESAL was created to develop and share knowledge and anticipate solutions between producers, and it's main focus has been related to disease and environment, where it has focused on monitoring of microalgae. Knowledge and related experiences from abroad have also been a very important factor in the KM/sharing and technology changes implemented in Chile. This is likely one of the main factors explaining the rapid growth of Atlantic salmon production. The establishment of research priorities, including the need for additional relevant knowledge, particularly related to the culture environment in southern Chile, is also important for the development of this sector, but its realization is not yet fully achieved. This situation has led to changes; for instance, a new R&D fund administered by CORFO, called INNOVA, which was created eight years ago, is supposed to provide important resources to develop R&D in such areas.

The main knowledge sources on fish disease are from abroad; for example, Norway, Canada, Scotland and the United States of America. These countries have much larger budgets and specialized research teams on such matters. While very useful, this knowledge may not be adequate, particularly in terms of relevance/adaptation to the Chilean environment (e.g. knowledge linked to sea currents at the production sites, models of dispersion, existence of reservoirs of pathogens in local fauna). All this information has to be developed locally, and there are several projects now examining these issues. Nevertheless, the

main “know how” (at least in terms of a biosecurity framework) on how to face a disease so dangerous as ISA was not adequately transferred and perhaps more importantly, the available knowledge was not put to practice, an argument presented by Asche *et.al.* (2009). The latter is especially relevant when considering that a large proportion of the production in Chile is in the hands of the same companies producing in Norway, Canada and Scotland, most of whom had already faced ISA in their farms.

Relevant development factors, problems and the role of information sharing

Location/concentration of the industry and provision of infrastructure: The industry in Chile developed in the south because of the favorable natural conditions existing in the area. Although the lack of infrastructure was a limiting factor, the development started where the limitations were less in relative terms. The availability of roads/basic infrastructure increased the probability of competitive costs for both inputs and outputs. Electrical power was also critically important for the operation of processing plants, ice production, etc.; other infrastructure-related support included access to labour, for instance for processing plants. The Chiloé Island area, which has been a center for this development, went through a variety of infrastructural bottlenecks that the industry was able to solve as part of the overall regional development process. New transportation technologies, such as the development of “wellboats”,¹⁵ combined with monitoring/control systems for oxygen, ammonia, and temperature of fish are good examples of local knowledge/technology adaptation and development that allowed further development of production into more remote areas where services were not available on site. Yet the movement of these vessels between distant areas, in the absence of biosecurity frameworks and adequately shared information, could have enhanced the spread of ISA.

The risks of maximizing production as only goal: The industry is regulated in terms of location; for instance, the amount that can be produced in each production site is regulated differently depending on the date of authorization of each concession. This was one of the advantages that the industry had for a very long time, allowing a more liberal approach to production and facilitating the rapid growth of the industry over time. However, despite early knowledge on carrying capacity concerns (e.g. Soto, 2000), this was not translated into plans and policies to regulate biomass per unit area in these inner seas. The industry at large has been often criticized for having focused mainly on increased production and short-term benefits, while over-looking relevant environmental and health considerations (Vera, 2010).

¹⁵ Wellboats are vessels specially designed to transport live fish and perform a diversity of aquaculture services such as harvesting, fish counting and even processing on board.

Fish health and quality of smolts: Another critically important factor, but very difficult to measure, is the quality of smolts. Key issues such as the establishment of common criteria to differentiate quality and to determine the most appropriate vaccines, and the development of more and improved selection criteria to improve the survival rates have to be carefully addressed and shared among farmers. Such issues are now being tackled by research partnerships composed of the private sector and Chilean universities and research institutions, all examples of new knowledge partnerships.

The ISA problem and BMP solutions: As mentioned, the deteriorating sanitary conditions were strongly linked to the appearance of ISA leading to huge mortalities of fish, the closing of more than 200 farm sites, an almost 1 billion dollar loss in exports and more than 20 000 jobs lost in the period between July 2007 and December 2009.

The increasing use of antibiotics in salmon farming in Chile for the last decade suggests that disease has indeed been a long-term problem in the sector. ISA has affected most other producers worldwide since 1990, and it has been known by producers in Chile. However, effective measures that could have prevented the introduction of the disease were not seen as possible given the large size of the industry, the possible and mostly unknown routes of the disease into the country, lack of adequate information sharing and the absence of regulation on these matters. Once the disease was identified in Chile, the spread was very rapid, and the main solution at that stage was to establish management areas that could help isolate and minimize its spread following procedures adopted by the authorities and by the producer's organizations. Despite these measures, spread of the disease occurred in a very short period of time and to a very significant part of the production area of the country.

The discussion of the possibility of developing a "management by area system" took place before the arrival of diseases such as ISA. However preliminary analysis suggested that this system was not feasible due to the potentially huge coordination required by the producers and the loss of independence in decision-making, which none was willing to sacrifice without a formal regulation. The problem was exacerbated by a lack of transparency combined with too much individual thinking and a lack of trust among the farmers themselves and between the farmers and the government (Asche *et.al.*, 2009).

The Chilean industry is now being reorganized under new regulations, learning in part from the experiences of other producing countries such as Norway and Canada, and where the same companies are involved, they are learning that greater sharing of knowledge across subsidiaries is valuable. Groups of producers operating in one area are organized and managed as one "aquaculture zone or neighborhood" and compliance is enforced by government agencies. These measures are now in place, and the biomass has also been reduced,

combined with coordinated fallow periods and the implementation of sanitary disinfection measures at critical points, all of which seem to have effectively reduced the viral counts and other pathogenic agents in the environment. The coordinated treatment of all farms and the cleaning of all equipment and the effluents of processing plants have also been very important in this process, leading to an expectation that future severe outbreaks should remain very rare and hopefully nonexistent.

BMPs to control future outbreaks have been applied and strongly reinforced since mid-2009. Some are mandatory by law, while others are voluntary through programmes and agreements between producers. All are monitored regarding compliance, which is critical to avoid the negative externalities or poor compliance by some producers.

Key lessons and the way forward

The lesson from this case study is that availability of knowledge “per se” was not enough; knowledge sharing, including the sharing of experiences, did not produce the change(s) of behaviour in time (Asche, *et al.*, 2009). Lessons have been learnt the hard way. How can this behaviour improve in the future? This question is very important but difficult to answer. The main lesson is that changes in practices that involve large investments, transparent sharing of information and new procedures are not very rapidly taken up, as the first adopters are not able to harvest the benefits. All must follow the same rules and bear the costs to reap the shared benefits of lessened disease. In order to make them really effective, they require compliance across the industry; for example, disinfection of transportation units. It is well known that such equipment can assist the transfer of disease, therefore the implementation of “clean procedures” requires that stakeholders at very different points during the production process are well informed to adopt the approved standards and follow audited procedures and regulations.

Traditionally the Chilean farmer has a very independent character; cooperation existed, but farm behaviour was mainly driven by the market and profits. However, the described sanitary catastrophe is forcing a much more collaborative approach among producers, one in which they now recognize a more ecosystem-based approach where all must cooperate with their neighbours and must consider other users of the coastal zones and watersheds. Relevant knowledge must be shared among these stakeholders. The primary objective of the activity must be beyond just farm production (FAO, 2010a) and look more seriously into long-term sustainability (and this includes economic sustainability!). The production at each farm is now managed as part of a wider plan of regulations which group farms in a given production area using defined boundaries that have been drawn on a map. Within each of these area clusters, the producers must share the relevant information and knowledge, coordinate their activities and inform others about the performance of their farms, their problems,

treatments, how are the fish behaving, etc. This move to stronger collaboration and more open reporting has established a new knowledge-sharing system which includes the designation of focal points who are named to the authorities as representatives whose duties include provision of up to date information on the situation in the area, current problems and measures for their solution. In summary, group coordination and examination of issues at this larger scale should improve understanding of the changing farming and environmental/oceanographic conditions (e.g. sea current effects on pathogen dispersal). The coordinator or entity that gathers all the information in a specific farming area (or neighbourhood) has to be able to understand/anticipate the knowledge needed, how/what to share and manage in a more integrated and participatory way involving all the concerned producers.

CASE STUDY 4

Investing in research, communications, training and extension for responsible marine aquaculture in Turkey¹⁶

Background

Turkish aquaculture is a good example of development without tradition. Since the late 1980s, marine finfish aquaculture production has focused on two major species, European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). In Turkey, marine aquaculture production mostly depends on coastal cage farming, and only a small amount is produced in land-based systems. Ninety-two percent of the cage farms are located in the Aegean Region, where geographical and hydrographical conditions are suitable for the species cultivated (Yucel-Gier, Uslu and Kucuksezgin, 2009). Turkey has great know-how and research capacity, but there is room for more sophisticated organization of these efforts, particularly with regard to implementation; closer linkages with users in general is also needed. R&D in aquaculture is largely done by university fisheries faculties and the research institutes of the Ministry of Agriculture and Rural Affairs (MARA), which is the main state organization authorized for fisheries and aquaculture administration, regulation, protection, promotion and technical assistance. There are 14 fisheries faculties providing undergraduate and graduate education in aquaculture and aquatic sciences. Universities run MSc and PhD research programmes, usually financed by those institutions themselves, or by the Scientific and Technological Council of Turkey (TUBITAK) and by the European Union (EU) Sixth (FP6) and Seventh (FP7) Framework programmes. A Directorate of Aquaculture and Fishery Research (TAGEM) has institutes in Trabzon and Antalya with the capacity to perform aquaculture research alone or in collaboration with other institutions. FP6 and FP7 programmes support research cooperation and integration of research efforts, promote mobility and coordination and invest into mobilizing research in support of other EU policies.

¹⁶ Prepared by G. Yucel-Gier.

Okumuş and Deniz (2007) pointed out that Turkish university research has focused upon fish genetics, fish health and management, fish breeding and the development of environmentally friendly aquaculture systems. In addition, it was indicated that Turkish “research results are often left as theses or dissertations or presented and published in scientific conferences and journals”; indeed, there had been a lack of extension work at the ministry level.

Currently, academic research must consider pan-Mediterranean projects, and the demands of the EU are of great importance in motivating and financing research. International institutions, such as the FAO, working in collaboration with MARA, have provided a welcomed stimulation of these efforts. Important projects cofunded by MARA and FAO have taken place. One of these was FAO project TCP-TUR-3101: “Developing a roadmap for Turkish marine aquaculture site selection and zoning using an ecosystem approach to management” (see Soto, White and Yucel, 2009). The objectives of this project were to examine the planning of marine aquaculture, to manage its development with necessary support and to suggest needful transitory actions for the relocation of fish farms. Moreover, the roadmap focused upon an ecological approach, moving towards integrated coastal zone management (ICZM) principles and objectives. A follow-up activity entitled “Indicators for sustainable development of aquaculture and guidelines for their use in the Mediterranean” was organized by FAO and MARA in 2009. This project involved consultation and interaction between the central government, scientists and stakeholders, especially those involved in the socio-economic, governance and ecological dimensions.

The general objectives of R&D for Turkish marine aquaculture within the Mediterranean-EU framework are to be achieved by synergy between research programme and infrastructure, thus avoiding duplication. There is a growing desire within Turkish marine aquaculture to belong to a dynamic and competitive knowledge-based economy linked to Europe. This is so as to be capable of sustainable economic growth which will generate better jobs and promote both social cohesion and respect for the environment. To this end, it is necessary to develop national and international platforms to disseminate research findings throughout society.

Salient points

Research programme: needs analysis

Universities collaborate with TAGEM and TÜBİTAK for the funding of Turkish research needs. There has been a marked tendency for TAGEM, the private sector and the universities to fund as a priority fish health, breeding, farming, genetics and feeding research. At the medium level of priority comes socio-economic research; organic (ecological) fish farming matters are left behind.

Under the EU FP6 program (2002–2006) there are several funded projects dealing with fisheries and aquaculture. There are interesting contrasts between

research topics chosen by the fisheries industry and the topics chosen by the aquaculture sector. Fisheries topics have long included the scientific basis of fisheries management and the ecosystem approaches. Research emphasis has also been given to gear selection, to monitoring and to control systems. For aquaculture, the topics usually had been connected with welfare, genomics, breeding, environment, feeds and diseases, rather than with governance and socio-economic matters. The objective of the FP7 program is the development of matters connected with food, agriculture and fisheries, and biotechnology. A European knowledge-based, bio-economy, (KBBE) is being built with the support of policies like the Common Fisheries Policy, (CFP). According to TUBITAK, Turkish researchers have creatively taken part in numerous pan-European developmental consortia (Celikkanat, 2007).

This is a summary of some of the main research outcomes over the period 2003–2008¹⁷

- A matrix for indicators of interaction between fisheries and fish farms was identified by an FAO AdriaMed project.
- “Indicators on sustainability”, coordinated by the Federation of European Aquaculture Producers (FEAP) and the European Aquaculture Society (EAS) were included in the FEAP Code of Conduct.
- A generic methodology to evaluate aquaculture sustainability, with a set of indicators was developed.
- Platforms for the communication and dissemination of EU research projects in fisheries and aquaculture were coordinated by FEAP and published.
- ECASA (Ecosystem Approach to Sustainable Aquaculture) (see www.ecasa.org.uk) evolved, with indicators, an ecosystem approach to aquaculture and a tool box to show links between the environment and aquaculture, together with an effective environmental impact assessment (EIA).
- A SUSTAINAQ project (Sustainable aquaculture production through the use of recirculation systems), funded by EU FP6, identified bottlenecks in Eastern European aquaculture and developed solutions through the use of recirculation systems.
- SEACASE (Sustainable Extensive and Semi-intensive Coastal Aquaculture in Southern Europe) (see www.seacase.org) developed environmentally friendly protocols, quality markers and certification to enhance product value.
- InDAM (Indicators for Sustainable Development of Aquaculture and Guidelines for their use in the Mediterranean) project worked on the cooperative selection of indicators and use guidelines for the sustainable development of Mediterranean aquaculture.
- The FEUFAR (Future of European Fisheries and Aquaculture Research) initiative successfully constructed a list of future research needs.
- EATiP (the European Aquaculture Technology and Innovation Platform) (see www.eatip.eu) highlighted the need for relevant and excellent KM as crucial

¹⁷ www.aquamedproject.net

for the success of aquaculture. This includes a wide range of activities: relevant R&D, dissemination, education, training and technology transfer, communications, networking, image perception of the products and the sector.

The central theme of these research programmes is the on-going development of ever more practical and sophisticated indicators.

One marked change in the direction of Turkish marine aquaculture research was the result of discussions at the Istanbul European Aquaculture 07 Conference. At that time, fish farmers in all coastal areas of Turkey were facing huge and unsupported relocation problems. This had been the result of new Ministry of Environment parameters for siting and monitoring. MARA was able to secure assistance from the FAO to examine the consequential logistical, planning and management problems. A “roadmap” was developed which amounted to a needs analysis with regard to the support, planning and management, and other related matters considered to be a priority and cost-effective research topics. In order to develop a more robust, competitive and sustainable Turkish mariculture sector for the long term, a series of research topics were outlined in this recent “roadmap” and, as such, it marks a significant change in research emphasis. The following research needs were identified:

- environmental management of marine aquaculture, including interaction studies between mariculture, other users of the coastline and the ecosystem;
- improved monitoring, such as by the use of standard methodologies for water quality and sediment analysis, and by developing carrying capacity models for Turkish coastal waters;
- the definition of a feeds and feeding programme;
- quality control of fry;
- fish health;
- investigating and developing the farming of new species such as shi drum (*Umbrina cirrosa*), turbot (*Scophthalmus maximus*), meagre (*Argyrosomus regius*) and brown meagre (*Sciaena umbra*) (these already are marketed in Turkey); further great potential is envisaged for sturgeon (*Acipenser* spp.), common octopus (*Octopus vulgaris*) and sponge;
- developing new technology – improved equipment and mariculture production systems;
- developing awareness of and methodologies for mollusc production;
- automated live food production systems;
- genetics – selection for improved traits (e.g. disease resistance, fillet yield, faster growth and improved feed conversion ratios (FCRs));
- developing assured quality and safety certification methods for the domestic market; and
- developing improved marketing images of mariculture products.

Training, extension services and communication

In Turkey, 14 fisheries faculties provide undergraduate and graduate education in aquaculture and aquatic sciences. Between 300 and 600 students graduated each year in the period 2001–2007. There are 25 other institutions for specialized higher education, known as Higher Schools of Vocational Development, preparing aquaculture technicians for the day to day needs of fish farming. There are also two specialist high schools for aquaculture. Training includes the techniques for the deployment of a complete monitoring strategy, which, hopefully, will eventually apply to all stakeholders. It is to be hoped that all stakeholders involved in the sector will cooperatively assist in the preparation of proposals for courses development, funded by the European Commission's Leonardo da Vinci Programme for education and training¹⁸ in parallel with the review of vocational high schools for aquaculture.

There is a need for increased public awareness of the true nature and benefits of a well-organized aquaculture sector, for the needs of food security, for the development and maintenance of environmental standards and for environmental protection. Much of this should be the responsibility of organizations such as the Official Union of Aquaculture Producers, the Mu la Fish Farmer's Association and the Federation of Aquaculture and Fisheries of Turkey. These support organizations have an increased role to play in the development of media programmes and interaction fora with other stakeholders. Moreover, the private sector must continue to be linked to training institutes, and producers should allow more practical in-service training courses for students to take place on their premises all the year round.

Lessons learnt and the way forward

The Turkish mariculture industry could benefit greatly from technology updating and access to information and technology that is generated and adopted in other countries, especially elsewhere in the Mediterranean. The use of carefully thought-out job specifications itemizing tasks and skills in which aquaculturists of all types and ranks can be supported and appraised should become fundamental to career development and to job satisfaction.

The main R&D challenge for Turkish aquaculture is to improve knowledge and information dissemination and extension services, in connection with putting research findings before a wider audience. To this end, the setting up of an organizational system for promoting two-way information exchange between fish farmers and local and central government on the one hand, and with the public and other stakeholders on the other is needed. With this objective, a task force should be established and indeed, the regular and planned coming together of all stakeholders is a desirable objective. Information flow between the producers and relevant authorities must be enhanced and the provision of state-of-the-art

¹⁸ http://ec.europa.eu/education/lifelong-learning-programme/doc82_en.htm

technical knowledge for producers must be made more readily available. One way to do this is to create an online database and information system in the Turkish language. Participatory input, feedback and awareness of the data to be used for decision-making by the relevant authorities need development at all levels from the ministries to the newest farmer recruits.

MARA-TÜBİTAK, with the support of the federation, unions and associations, should be the responsible agent for constructing a repository for aquaculture information. Modern technology needs to be applied for communication and dissemination of ideas, and to facilitate timely communication and implementation of the latest research results. There are particular opportunities in the areas of text retrieval, bibliographic services, video and photo databases.

CASE STUDY 5

Knowledge, information and dissemination in aquaculture: European position¹⁹

Background

Research and development

It has been increasingly recognized in Europe that improving communication between the different actors within and affecting the aquaculture sector is a crucial issue for the improvement of “knowledge management”, a term that encompasses the title of this case study. Specifically, this case study refers to knowledge generated by research actions and projects achieved within the European arena.

In Europe, only 7–8 percent of research is financed through European funding; this means that 93 percent is funded nationally and usually targets national interests. Consequently, it is considerably easier to organize dissemination and communication of European work – since achieving effective dissemination is a basic condition of grant agreements for research work that receives European funding.

The generation of new knowledge from research and technological development (R&D) actions in aquaculture is made basically on four levels:

- R&D achieved in institutes and universities – targeting knowledge generation, scientific publications, patents;
- R&D achieved in corporate structures (e.g. feed and pharmaceutical companies) – targeting the manufacture and sale of new products to the aquaculture sector;
- R&D achieved on the farm – looking to improving performance, productivity and competitiveness; and

¹⁹ Prepared by C. Hough.

- R&D made in another field but where an opportunity is seen for application in aquaculture – serendipity.

Results of knowledge generated within the academic research sector, unless covered by patents or specific reasons of confidentiality, are usually published in specific scientific journals and may be the subject of communication within conferences. For this science to be able to get through to the farmers, communication/dissemination networks are needed, since it is rare for individual farmers to attend scientific conferences.

Cooperation has always existed between industry and institutional research, particularly if the industry in question does not possess its own research facilities and related human capacities. Inevitably, such cooperation – without public financial support – will be tied to confidentiality and the (potential) commercial advantage of the company that finances the work.

The achievement of research on the farm can be very fruitful, but the results are usually kept in-house since these will usually be considered as the commercial advantage of the farm in question. Since such research tends to be achieved in “operating” rather than “scientific” conditions, it is also rare that such work is published in scientific journals.

Overall, it is the evolution of cooperative research – such as the specific European programmes (see <http://cordis.europa.eu>; www.feap.info) that involve small and medium-size companies with RTD institutes – that has stimulated a broader approach within the European research sector. Projects within these programmes require the creation of a consortium that is responsible for achieving the work proposed and managing the intellectual property generated. The project objectives have to include clear benefits for the industrial sector involved.

Salient points

Dissemination of knowledge

There are several different components that comprise knowledge and information which require communication actions. These might, as examples, be related to markets, policies, legislation, technology, research or simply knowledge and information about the sector itself. For each component, different structures and networks have evolved and are active at present.

Many of the subsectors of fish farming in Europe have developed as a result of knowledge transferred from successful R&D. As examples, within the major species produced, one can cite the husbandry of salmon, seabass, seabream and turbot. On systems technology, one can refer to cage and tank design, water recirculation technology, feed distribution systems and farm management software.

The knowledge generated for these topics has been disseminated through different networks, which can be broadly described as:

- academic (e.g. scientific journals, scientific meetings);
- academia-industry mix (e.g. conferences, workshops, seminars);
- industrial context (e.g. association meetings, industry-organized workshops)
- development (e.g. FAO, the Organisation for Economic Co-operation and Development (OECD), International Union for the Conservation of Nature (IUCN), Network of Aquaculture Centres in Asia-Pacific (NACA), Worldfish Center)

The formal academic networks focus on scientific excellence, represented by peer-reviewed publications and congresses or conferences organized by academic bodies or societies. Inevitably, much of the specific information generated remains within the academic community since few practicing aquaculturists subscribe to specialist journals or attend purely academic conferences.

Internationally, the academia-industry mix has been developed through the conferences and publications of organizations such as the European Aquaculture Society (EAS) and, at a global level, by the World Aquaculture Society (WAS). At another level, involving policy-makers as well, the FAO makes significant contributions through its regional structures (e.g. the European Inland Fisheries Advisory Commission (EIFAC), the General Fisheries Commission for the Mediterranean (GFCM) and its committees (e.g. the Committee on Fisheries (COFI) and its subcommittees on aquaculture and trade)), its workshops, publications and projects. More recently, other international organizations such as the OECD and the World Organisation for Animal Health (OIE) are contributing through their specific interests in aquaculture.

Within the industry, the structuring of representation through associations has accompanied the sector's development. All European states have regional and national associations that represent the professional sector that is present; most European states have a national association that either represents aquaculture as a sector (e.g. Spanish Marine Aquaculture Producers) or identifiable species producers (e.g. Scottish Salmon Producers). As aquaculture has developed and grown, consultation between governmental and sectoral representatives has increased, generally with the ministry responsible for aquaculture. Usually, this has also been accompanied by links to national scientific institutes and universities that work on aquaculture issues.

This position has developed further with inter-professional organizations that include upstream/downstream sectors and related stakeholders (e.g. the Danish Aquaculture Organisation and the French Inter-professional Committee on Aquaculture). In Europe, since 1969, most of the associative structures representing professional fish farmers have been members of the Federation of European Aquaculture Producers (FEAP), which represents the interests of

these associations at the European level. This representation is to provide a communication bridge to the European bodies, such as the European Commission (EC), the European Parliament and the Council of Europe. Within this scope, the FEAP is a member of the EC's Advisory Committee on Fisheries and Aquaculture (ACFA) which examines and debates a wide range of legislative and practical issues that affect the professional sector.

In 1992, a new initiative was created – AquaTT (www.aquatt.ie) – under the EU COMETT (Community action programme in Education and Training for Technology) programme as a University Enterprise Training Partnership (UETP) for the European aquaculture industry. The initial proposal arose from the identification of a need to systematize, coordinate and develop the training requirements of the professional sector through a single body.

1. In Europe, there were thus three European organizations active in “knowledge management”, each with their specificities and target audiences. From 1998 onwards, FEAP, EAS and AQUATT (Aquaculture Technology and Training Network) have worked together on a number of successful projects that focused on dissemination and knowledge transfer (Aquaflow²⁰, Profet and Profet Policy²¹).

The approach to achieving these projects has shifted with time, as a function of changing communication practices (from fax to the Internet) and conditions (wider consultation, transparency). A major change was to move from maximal dissemination of R&D results towards identifying problems and needs for effective R&D through targeted consultation and discussion.

“Profet Policy” not only provided a platform for the communication of R&D results and their relevance to European policies, it also gave the possibility for wider debate on the state of the sector and its objectives and needs.

Adapting to change

This change was reflected in the recognition that all members of the aquaculture value chain should be involved in determining future development policies and actions, defining a vision for the future and the actions needed to attain this. This position was promoted actively within the European economy by the creation of European Technology Platforms²², an action that started in 2004.

The concept for these was:

- to provide a framework for stakeholders, led by industry, to define R&D priorities, timeframes and action plans on a number of strategically important issues focusing on Europe's future growth, competitiveness and sustainability objectives;

²⁰ See www.aquaflow.org

²¹ See www.profetpolicy.info

²² See http://cordis.europa.eu/technology-platforms/home_en.html

- to play a key role in ensuring an adequate focus of research funding on areas with a high degree of industrial relevance, by covering the whole economic value chain and by mobilizing public authorities at the national and regional levels; and
- to address technological challenges that can potentially contribute to a number of key policy objectives which are essential for Europe's future competitiveness.

In fostering effective public-private partnerships, technology platforms should have the potential to contribute significantly to European strategies and the use of knowledge for growth. Current contributions show them to be powerful actors in the development of European research policy, in particular in orienting European research programmes to meet better the needs of industry. To achieve this concept, the timely development and deployment of new technologies, the application of new technologies that have a clear view to sustainable development and the restructuring of traditional industrial sectors are objectives of particular application to the aquaculture sector.

The European Aquaculture Technology and Innovation Platform

Discussions on the potential for the creation of a European Aquaculture Technology Platform started in 2006, mobilized by several important players in production, research and feed manufacture. The immediate challenge was how to combine competing interests from the different sectors within a structure that has to have common goals for a common interest.

Defining these goals and achieving clarity in the objectives of the platform took time, particularly since the actions were voluntary. It is fair to say that the initial meetings set the scene, but that the translation of broad ambitions into specific progress and realization of the platform took time. Improving the competitiveness of European aquaculture, based on knowledge and skills, and assuring its long-term sustainability was and remains the core objective of this initiative.

Achieving this was made by using a core group of interest representatives from each subsector of the aquaculture value chain (e.g. producers, researchers, feed manufacturers, processors, fish health specialists, equipment suppliers), who met regularly to define a draft vision document for the future, based on identifiable thematic areas of interest.

While specific scientific and technical issues were identified rapidly, a common issue that was addressed by all participants was the improvement of the efficiency in managing the distribution of knowledge. Consequently, in looking at an operating structure for the platform, five “technical” thematic areas were designated:

- product quality, consumer safety and health;
- technology and systems;

- managing the biological lifecycle;
- sustainable feed production; and
- aquatic animal health and welfare.

Alongside these, three “horizontal” thematic areas were proposed, being:

- integration with the environment;
- socio-economics and management; and
- knowledge management.

In November 2007, a stakeholder meeting of the proposed Technology Platform met to discuss the draft vision document, its actions and structure. At this point, it was agreed to create a formal structure, unlike most other European Technology Platforms, that would be registered as a non-profit association. This decision was motivated by the recognition that many of the goals are long term and that full sectoral commitment was needed for success. In addition, this meant that an adequate fee structure would allow a level of financial autonomy that is needed to promote and organize the platform. The European Aquaculture Technology and Innovation Platform (EATiP²³) was officially registered in December 2008 and currently has some 60 members from the corporate, research and associative and representative sectors.

As described previously, FEAP-EAS-AQUATT had been involved together in European actions targeting the dissemination of knowledge. With the experience of the development of EATiP, a new approach was formulated as a European initiative that is coordinated by EATiP itself. This project, titled “Aquainnova”, will look to achieve four key objectives:

- create an operational framework for dialogue, between the value chain of the aquaculture industry, the research community and the policy-makers,(and that this be based on best governance practices);
- exploit the potential for innovation and technological development in the European aquaculture value chain;
- actively promote the exploitation, dissemination and communication of aquaculture R&D achieved in the EC; and
- improve how RTD and innovation knowledge is managed, disseminated and transferred.

This action will thus not only give a very close focus on how R&D and innovation knowledge is currently managed, both within the academic and industrial sectors, but also assess the best mechanisms for dissemination and communication within the different stakeholder communities.

²³ See: www.eatip.eu

Lessons learned and the way forward

Effective communication depends on careful identification of the target audience, followed by the use of the correct tools/facilities to reach effectively the audience identified. Translating this relatively simple concept to an audience as diverse as the different stakeholders in aquaculture is a big challenge.

Efficient networking, for all interested parties, is essential for the best KM, and the use of existing formal and informal networks is integral to this.

As a consequence, whereas the individual networks of different European bodies have their identifiable target audiences (i.e. their members and participants) and interests, there has been visible growth in a more participative approach to addressing issues of common importance.

While the EATiP is in its early days, it appears that the grouping of different players and interests within a structure that provides coherent and consistent objectives for aquaculture development will assist efficient KM and associated communication actions.

CASE STUDY 6

Investing in knowledge and communications: NACA training and extension experiences²⁴

Background – NACA history and mandate

The Network of Aquaculture Centres in Asia-Pacific (NACA) was founded in 1989, with seven member governments, as an intergovernmental organization and is now composed of 18 member governments which together produce over 90 percent of world aquaculture production (by volume). With a mandate to improve the livelihoods of small-scale farmers and contribute to food security and poverty reduction through sustainable aquaculture development and aquatic resource management, NACA seeks to provide a range of training and extension services both through its secretariat, its lead centers and its other partner organizations of the member governments.

Salient points

A brief summary of Asian training and extension (T&E) to date

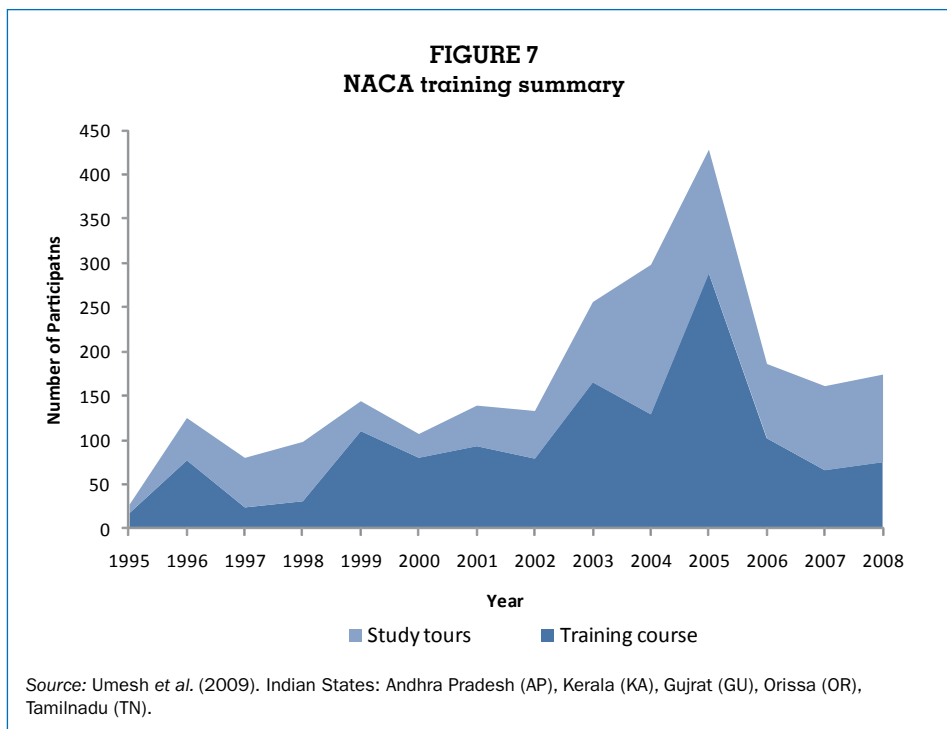
Education programmes for fisheries appeared in the Asian region at the turn of the last century. After almost a century of effort up to 1980s, a variety of deficiencies in the fisheries education systems were still a major issue (De Silva, 1988, 1991; De Silva, Sim and Phillips, 2000). A faster growth phase of the aquaculture sector in Asia started in the 1980s, and so did aquaculture education (AE). Consequently, the Asian region witnessed a rapid expansion of formal degree education in fisheries, aquaculture, aquatic resources

²⁴ Prepared by Yuan Derun, F. Brian Davy, S. Wilkinson and S.S. De Silva.

management and related disciplines, even to the extent that such courses began to be provided by the distance mode, primarily catering to those already in employment but seeking to enhance their knowledge. At the turn of the new millennium, deficiencies seemed less of a major concern in AE with the shift to a wider diversity of aquaculture practices and an associated diversity of AE combined with changing demand. These were leading to a greater need for AE to address a wide range of issues such as social development, sustainability and resource management (see De Silva, Sim and Phillips, 2000). Training, with its quick response to industrial technology needs and focus on specific skill development and application with flexible and efficient learning approaches has also developed into a highly important educational sector in aquaculture. To date, most educational/research institutes and government extension agencies conduct a wide variety of training activities at the national level; as well, some international/regional training programmes were established by various Asian regional organizations such as the South East Asian Fisheries Development Center (SEAFDEC), Asian Institute of Technology (AIT) and NACA, among many others.

NACA continually tries to respond to the demands of its member governments through the development of new training options. This strategy builds on the diversity of activities and skills of member governments, all of which offer an increasingly wide mix of training options, most of which continue to evolve in response to the changing needs of farmers, governments and other stakeholders. In brief, aquaculture development in the region has been characterized by rapid advances in production technology and diversification of production systems, followed by a more recent marrying of science and social aspects related to management that has led to the development of, for example, BMPs and a cluster approach to their adoption. The latter is able to prepare farmers to comply with emerging issues such as food safety and quality, international trade, environmental concerns and climate change. Consequently, aquaculture training has also been challenged to keep up with and adapt to this rapidly changing mix of issues. These demands include the increasingly diverse training needs, coupled with an increasing diversity of backgrounds of the candidates seeking training. NACA's latest venture into training is to combine with other interested partners to provide a course for developing skills in business management principles for small-scale farmers – the backbone of the aquaculture sector in the region.

Overall, NACA seeks to meet these demands with innovative training approaches that optimize the increasingly constrained training resources. A review of the NACA experiences to date in conducting training in aquaculture for more than the past decade can be summarized as follows: more than 3 000 professionals from 30 countries and from an equally wide mix of backgrounds/organizations were trained in a wide variety of training courses and study tours. In addition, this review outlined some of the history of these training approaches and



then examined the lessons learned from the training experiences. In brief, it was suggested that knowledge networking and partnerships that encourage continued shared learning mechanisms to better utilize the diversity of knowledge and training experiences of NACA and its partners have provided a valuable resource. The past supply of training is being examined as part of an evolving examination of future training, including an initial examination of mechanisms to further strengthen these efforts. Optimization of the regional aquaculture training resources, improvement in training efficiency and enhancement of the capacity of training institutions to cope with new challenges coupled with redesigned evaluation and other feedback mechanisms are being examined as part of this review of training efforts.

As can be seen in Figure 7, study tours (e.g. white-leg shrimp farming, feed manufacturing) and regular training courses (e.g. integrated fish farming, marine fish seed production, intensive shrimp farming, shrimp disease management) (see www.enaca.org/ for more details) have been the main training options provided to date. The mix of study tours and training courses continues to evolve, with a priority for study tours likely driven by the large number of development projects in which study tour funding mechanisms are a priority. Although there was a peak demand in 2005, study tours continue to be in high demand throughout the region for a variety of aquaculture stakeholders from many member and non-member countries.

Tools

Training data analysis (e.g. tracer studies) is being coupled with the development of a variety of training tools, and improved evaluation methods are a priority to better guide the development of a new set of capacity development programmes.

New directions

Although the demand for aquaculture training continues to increase, assessment of these needs in order to better provide optimum training services remains the major challenge. NACA is exploring various possibilities for a systematic assessment of aquaculture training needs in the region, including other types of feedback from training participants, better use of staff travel information, regional reviews and workshops, and more proactive interaction with the business sectors (as part of value-chain analysis research).

The current training directions of NACA focus on and are in line with global aquaculture development trends coupled with a look at emerging issues related to small-scale farmers, e.g. lack of adequate business management knowledge and skills, increased competitiveness in a dynamic global environment and increasingly stringent food quality and safety requirements. Apart from continuously organizing training courses on high-demand topics and highly relevant topics such as marine finfish production, NACA is developing a variety of new training courses, for instance on aquaculture business management for small-scale farmers, and BMP and aquaculture certification, respectively. As well, NACA is collaborating with international and regional partners to ensure that the training materials better reflect NACA's decade-long experience in promoting sustainable aquaculture in the region while maximizing the use of international expertise. Skills development, implementation approaches and reaching wider audiences through the Internet and other information and communications technology (ICT) will be new foci for this work. Interested readers should see, for example, the Aceh Indonesia trials on the development of aquaculture service centers using voice over Internet technology (VOIP) to share knowledge among others in their association (Ravikumar and Yamamoto, 2009). Also, NACA has been increasingly experimenting with farmer-based approaches such as farmer to farmer exchanges (e.g. catfish farmers visiting Indian shrimp farmers (NACA News, 2009)).

NACA will continue to provide aquaculture study tours in the region. In addition to examination of farming practices, more in-depth analyses and system comparisons will be added to field visits. Training more closely linked to the major development trends and increasing capture of success stories and lessons learned will be highlighted.

The divide isn't just digital: any discussion of Internet technologies for small-scale farmers needs to acknowledge its limitations. Internet penetration is low

in rural areas and also in low-income-earning groups. It is extremely low among people who are both rural and poor. However, having said that:

- Exactly the same is true of printed publications, training courses and most other “traditional” communication/extension approaches, whose application is severely limited by their high costs of production and distribution, literacy and labour constraints.
- Internet penetration is growing rapidly and continues to accelerate, particularly among young people. China already has more Internet users than any other country. Asia already has more Internet users than any other region (Tables 4 and 5).
- Computer prices continue to fall, particularly for small mobile computing devices (phones and netbooks).
- Mobile phones and satellite Internet services are bringing broadband Internet speeds even to the remotest of areas, thereby bridging the physical aspects of the “digital divide”, if not the economic ones.
- It is likely that nearly all computers and phones will eventually be networked.

The Internet is not yet “mainstream” enough for direct communication with most farmers in the region. However, it is an important tool for extension agents and others who work with rural communities. Initiatives such as the “Aquachopals” of India or the “One Stop Aqua Shops” and Aceh Aquaculture Communications Centre piloted by NACA have demonstrated that facilitated access to the Internet can be a useful and feasible way to provide services to farming communities. For example, communications links to remote diagnostic expertise and extension services, and audio/video presentations are useful to overcome literacy barriers.

TABLE 4
The Internet: no longer the province of developed countries

	Asia	World
Number of users	657 million (41.2%)	1.596 billion
Average penetration	17.4 %	32.1 %
Growth since 2000	474.9 %	342.2 %

Source: Internet World Stats, Q1 (2009).

TABLE 5
Top five Internet countries

Country/Federation	Number of Internet users (millions)	Penetration (% domestic population)
China	298	22.4 %
European Union	297	60.7 %
United States of America	227	74.7 %
Japan	94	73.8 %
India	81	7.1 %
Brazil	67	34 %

Source: Internet World Stats, Q1 (2009).

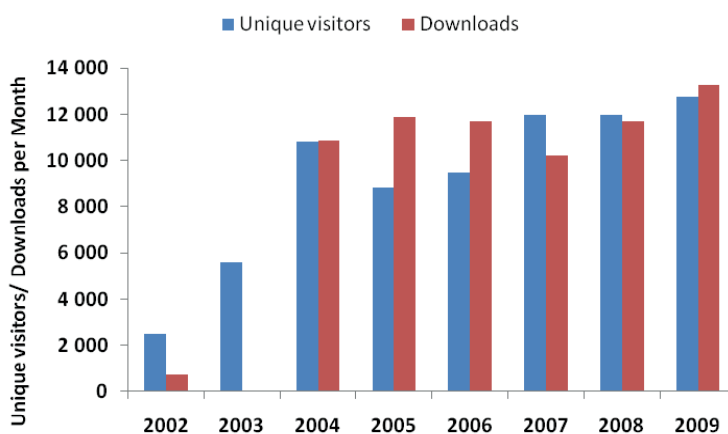
NACA's Website experiences

NACA established its first static Website in 2000. Starting from 2001, the organization adopted a policy of making all publications available for free full-text download from the Website in portable document format (PDF). By the following year, the number of publications distributed in electronic form had exceeded that of hard copies. It quickly became apparent there is an enormous thirst for information on aquaculture development.

NACA moved to a dynamic Website in 2004, using a free open source content management software (presently ImpressCMS, www.impresscms.org), which automated much of the publishing process, making it faster and easier to publish new information. Improvements to the quality of content offered and frequency of publishing led to a large increase in Website traffic (Figure 8). Today the Website attracts around 15 000 unique visitors and 200 000 page views per month, and around 150 000 publications are served per year. The annual operational cost for this is around USD10 000, the bulk of which is for rental of a dedicated virtual private server. The Website has become NACA's most efficient tool for sharing information/knowledge and raising awareness of the organization's activities among participating research centers. However, its application to rural farmers is far more limited.

Recently, NACA has begun publication of an e-mail newsletter which provides subscribers with links back to new content on the Website, boosting traffic by around 25 percent. NACA has also begun to experiment with publishing audio recordings of technical presentations in MP3 format and production of video

FIGURE 8
NACA Website users. Unique visitors refers to unique "IP address" therefore excluding multiple visits from the same computer while there could be multiple downloads from the same IP address (computer)



training materials via Youtube. Another area of development is integration of tools to allow people to share NACA's Website content with their own contacts via social networking services such as Facebook and Twitter.

An integrated approach: new and old media are complementary

Although the Website has proven to be a highly effective communication tool, NACA still produces printed editions of publications, runs training courses and workshops, and does all the things it has traditionally done to communicate with people. Our stakeholders vary widely in their capacity to access and utilize different media, and a blended approach is necessary to maximize accessibility. We try to cross-link media; for example, printed publications carry advertisements for resources on the Website and vice versa to maximize awareness, accessibility and sharing.

The Website has allowed NACA to reach out to more people than ever before, but to a large extent this is a new and different audience. The Website is just another tool in the box, one that will become increasingly more valuable with time, and one that works best used in concert with other media.

Key messages and the way forward

In the past decade, NACA has sought to provide a variety of training services, while the region has witnessed rapid changes in aquaculture development often characterized by rapid advances in production technology, diversification and specialization of production systems. Additionally, there has been a gradual standardization of production processes and an increasing need for rapid adaptation to emerging issues such as food safety and quality, international trade, environmental concerns and climate change. Financial support for extension is facing a variety of challenges, mainly financial constraints (see, for example, FAO 2010b). Consequently, increased production is often not the main priority now; problems in the sector relate to sustainability and meeting the needs of the international market place. Consequently, the NACA Education and Training Program and other training institutions are being challenged to keep up with and adapt to this rapidly changing mixture of issues. In summary, the main future challenges include: the increasing diversity of training needs which no single institution is able to handle properly, the increasingly diverse trainees' backgrounds, the limited training resources and increasing costs, and a less predictable life expectancy of so-called regular courses and enrolments. Additionally, more and more training demands are driven by ad hoc requests, leading to quality concerns and difficulties in needs assessment at different levels around changing demands, timing, and costs. Related issues might also include use of scientists vs. trainers and the use of ICT and particularly the cell phone and various other learning and knowledge-sharing tools. NACA is experimenting with expanded use of ICT; some Web-based training and knowledge sharing models are being developed and mechanisms are being sought to make more free information available to wider sets of recipients, often through expanded and strengthened links among partners.

Overall evaluation of the case studies

Some lessons learned

The case studies described in this review (see Table 6) reaffirm the fundamental importance of knowledge and its management (KM). The case studies also confirm that we have not really looked at this issue adequately, and as we plan for Aquaculture 2020, we should develop a renewed approach to KM. Such an approach should better recognize the significant challenges in dealing with the enormous amount of information/knowledge and the differential and often limited capacities of the various stakeholders to deal with this knowledge. Our review confirms that approaches such as knowledge brokers, knowledge platforms and related mechanisms for sharing, digesting and generally assisting this knowledge management process are working but more needs to be done. Follow-up efforts should give more recognition and pursuit to action research on the various gaps, such as more effective utilization of local or indigenous knowledge and the improved use of links to other stakeholder knowledge experiences. Knowledge sharing seems poised to expand at all levels and scales, but we can expect a variety of challenges in optimal knowledge sharing. This scenario is driven not only by the rapid growth in aquaculture, but also by the increasing number of stakeholders. The accompanying drivers/pressures (e.g. market forces and globalization) provide good examples of these changes, changes that increasingly cross spatial, time and level boundaries. These issues have generally received little attention to date by the aquaculture community. We are also entering into an era where many questions are being increasingly asked about funding priorities, for example, for research. In such a context, the sector is best advised to develop some guidelines on more effective evaluation of research outputs (in relation to funding inputs), as well as develop qualitative measures of the impacts of research on the sector.

Table 6 suggests a set of further overall lessons learnt and a variety of related observations:

- As culture systems developed, and particularly with the consequent intensification, disease and related health management knowledge became an increasingly important issue in all cases, and these changes have mainly taken place in the last ten years and are still on going. In most cases, inadequate knowledge sharing and management was a major constraint, but this lesson apparently needs to be relearned in each instance. This is perhaps one of our most startling findings. This poor knowledge sharing seems driven by competition for markets; stakeholders should take note that improved knowledge sharing on key issues like disease may outweigh traditional individual market-driven competition approaches. Moves toward a wider set of sustainability concerns seem likely to follow a similar trend.
- Improved examination of social organization, participation and shared learning among farmers is suggested, particularly at the implementation level. In general, social science inputs in aquaculture seem slow to develop and the reasons for this remain unclear.

TABLE 6
The six cases examined through a knowledge-communications (K&C) lens, in chronological sequence, including reference to the Bangkok Declaration.

Issue	Viet Nam	India	Turkey	Chile	FEAP Europe	NACA Asia
Early history, common starting points, constraints	<ul style="list-style-type: none"> Modest production levels via traditional cage culture system in Viet Nam & region 	<ul style="list-style-type: none"> Traditional shrimp farming in coastal lagoon systems; disease an increasing problem 	<ul style="list-style-type: none"> Turkey & Mediterranean seabass/ seabream cages start in the 1980s Quick growth ICZM conflicts, K&C strengthening needed 	<ul style="list-style-type: none"> Cage culture in Chile region with very rapid growth over the 1990s Salmon farmers well organized in farmers association & thought to be well-positioned against crises 	<ul style="list-style-type: none"> Recently established as a regional producer-led group Recognition of K&C barriers 	<ul style="list-style-type: none"> Early regional body with significant training/extension (T&E) including partnerships with Viet Nam & India (cases cited here)
What changed? Main current knowledge management (KM)/uses	<ul style="list-style-type: none"> Rapid increase in production around 2000 when seed supply (research knowledge) & new pond culture systems (farmer knowledge) developed 	<ul style="list-style-type: none"> Marked reduction in disease problems led by new science-based BMP collaborative system started in 2000 in Andhra Pradesh driven by strong participation & cluster organization of farmers supported by creation of a new national organization (NaCSA) 	<ul style="list-style-type: none"> Relocation: on shore to off shore in face of tourism demands & environmental impact Piloting of stakeholder K&C participation through development of indexes for sustainable aquaculture Similar to other cases where good science played an important role 	<ul style="list-style-type: none"> Imported "know how" from main salmon countries, as the same companies were involved Government-funded research increasing but with limited impact on aquaculture production 	<ul style="list-style-type: none"> Refining knowledge platform around five main KM issues Strong industry links; use of value chain thinking 	<ul style="list-style-type: none"> Stronger government & research knowledge links Regional knowledge sharing (T&E) blended approach to K&C use of Internet and new technologies with more traditional study tours exchanges, etc.
K&C: Who generates main knowledge? Who disseminates knowledge? Who uses this knowledge?	<ul style="list-style-type: none"> Farmers, researchers, government develop sharing & using knowledge 	<ul style="list-style-type: none"> Cluster organizations of farmers effective in sharing of knowledge. Farmers with local agencies used science for health KM, BMPs NaCSA working closely with farmers on key knowledge issues; e.g. certification and international marketing 	<ul style="list-style-type: none"> Private sector has large role in the generation of new knowledge. Partnerships between university-farmers and government, but consumer needs more info 	<ul style="list-style-type: none"> Important role of the private sector in the generation of new knowledge 	<ul style="list-style-type: none"> Work with farmers at the aquaface; risk assessment initiated; leads to science-based BMP development 	

TABLE 6 (Continued)

<p>What is working?</p>	<ul style="list-style-type: none"> - Good science around the key knowledge inputs of breed, feed, disease, etc. 	<ul style="list-style-type: none"> - Good focus on key farmer problems; farmers organized and collaborating/ sharing knowledge 	<ul style="list-style-type: none"> - Good science similar to Viet Nam experience needs media dissemination to encourage full awareness of health, food, environmental impact, etc. In-services training courses needed at all levels 	<ul style="list-style-type: none"> - New management plan set up to confront disease (ISA) problem but too early to judge effectiveness 	<ul style="list-style-type: none"> - Regional networking & neutral broker concept 	<ul style="list-style-type: none"> - Training courses & Website use have continuing strong demand - Involvement with farmer clusters; government, research institutions
<p>Main challenges. What is not (yet?) working and potential solutions or innovations in KM; future implications</p>	<ul style="list-style-type: none"> - Farmer to farmer & social organization shared learning still in early stages of development 	<ul style="list-style-type: none"> - Value-added marketing & certification coming but takes more time 	<ul style="list-style-type: none"> - K&C platforms needed to enhance current limited economic, marketing, know-how - Governance & implementation efforts need opening-up and updating - Training & extension needs more effort - Aquaculture research strategy needs horizontal & vertical revision - ICZM K&C planning involving all stakeholders needs to be developed 	<ul style="list-style-type: none"> - Disease-related knowledge exchange between farms & open nor rapid - Farmers association as a knowledge-sharing platform needs work - Government regulatory efforts inadequate - Absence of an effective biosecurity framework - Government increasing role in funding research - Government & foreign-owned companies knowledge sharing inadequate - Need stronger "knowledge broker" organizations & a new cluster approach to collaborative farming 	<ul style="list-style-type: none"> - Shared learning using platforms or other mechanisms is slowly starting 	<ul style="list-style-type: none"> - Many small-scale farmers remain difficult to reach; continue to experiment & learn/adapt - Disseminating the concepts to other countries & commodities - Strengthen the science-based elements/approaches
<p>Main Recommendations</p>	<ul style="list-style-type: none"> - Continued effort on knowledge sharing among better organized farmers & other stakeholders, including government 	<ul style="list-style-type: none"> - Improving collaboration & shared learning within & across levels (i.e. farmer to farmer, state to state and nationally) works 	<ul style="list-style-type: none"> - International partnerships communications platform experiences positive & expanding 	<ul style="list-style-type: none"> - Increase transparency & efficiency in the transfer of information among companies & between companies & government - Increase sense of the "common good", both public and private 	<ul style="list-style-type: none"> - Continue blended approach to T&E using new & traditional tools - Give farmer innovative aspects to management - more prominence & disseminate widely - Main problems linked with funding & coping training needs 	<ul style="list-style-type: none"> - Continue blended approach to T&E using new & traditional tools - Give farmer innovative aspects to management - more prominence & disseminate widely - Main problems linked with funding & coping training needs

- KM drawing on and sharing lessons learned across a widening set of knowledge systems and resources is needed; e.g. more comparative work examining the potential use of other knowledge sources from outside players of the usual aquaculture partnerships, for example, the World Bank Knowledge for Development (K4D) Group.
- Movement away from a “market-first development model” to a more shared-learning model seems to be happening but needs considerable more work, including promotion as well as seeking a better understanding of costs/benefits.

Understanding change processes

Overall, aquaculture has been, and seems likely to continue to be, a story of growth – extremely rapid growth in some cases (such as outlined in our Chile and Viet Nam cases), but growth that has both positive and negative impacts. In addition, our review suggests that there are much slower development phases, likely of 25–40 year cycles, that have taken place. Such underlying slow change processes have received negligible examination to date but could also provide important insights to improved knowledge on changes in aquaculture and its improved management.

Our selected case studies raise a variety of other growth questions around knowledge production and particularly, its communication and use, for example, in new training and extension knowledge-based thinking, examining how best to get knowledge into the hands of those that most need it, often across a variety of barriers (e.g. language, capacity and access differences), linked to a better understanding of its communication among the changing audiences. All of this is taking place as aquaculture continues to attract an increasing variety of new stakeholders, as it attempts to deal with a widening set of change processes often involving a complex mix of governance and social changes. In recent years, the aquaculture scene has been one of increasing confrontation, often driven by limited understanding and sharing. We suggest that more aquaculture stakeholders need to better understand some of these knowledge processes and expand efforts on newer concepts such as knowledge translations. All are suggested as potential knowledge strategies that are likely to be increasingly critical to the sustainable development of aquaculture and its improvement in attaining the goals set out in the Bangkok Declaration.

Indigenous and farmer knowledge and links to major users

Indigenous farmer-based knowledge and innovation including traditional knowledge has been critically important to the development of this sector. Of course, some of this knowledge has a very long history, over thousands of years in places such as China. However, KM (for example, shared learning at the farmer level in aquaculture) is little studied. This seems to be a niche needing more work, perhaps making better use of the new information and communications tools (ICT) to document and share knowledge at the farm level in particular.

Recently, it has been highlighted that the transformation of Viet Nam catfish farming from a cage-based culture system to a pond-based system was the result of an innovation of a single rural farmer, who has gone on to be one of the main producers of Vietnamese catfish (Anon., 2009). However, this line of thinking seems to have a limited knowledge base to date; perhaps aquaculture needs to reach out more to social and related sciences to encourage more work in this area.

Good science and aquaculture research

In more recent years, for example from the 1970s onward, appropriate research or what we are calling “good science” has played an increasingly important role in aquaculture development. An example of this is our case study on the breeding successes with striped catfish in Viet Nam and how this international partnership of breeding researchers seemed to be one of the critical change events in stimulating the phenomenally rapid expansion of this catfish production system (for more details on this history, see the Viet Nam case study). However, our knowledge base still has significant gaps, for example, on traditional knowledge related to biodiversity and to aquatic genetic resources more generally (e.g. see Phuong and Oanh, 2009). Also, we note the very interesting management ideas coming from some of the traditional fisheries management research (e.g. in Sabah, Malaysia); however, wider sets of such data are extremely limited.

Equally, development of science-based BMPs and their application in management has brought about positive results (Umesh *et al.*, 2009). Perhaps this thinking has to be adopted in a wider set of commodity chains and farming systems, with the consequent outcome of not only enhancing economic viability but also being an indirect approach to meeting food quality and food safety requirements of the market place.

Knowledge translation and use

Knowledge translation (KT) is a concern, particularly knowledge that fits well with the needs of aquaculture producers (as highlighted by most of our case studies, for example, those for Europe, Chile and Turkey). We return to this issue later as we discuss the concept of “aquaface thinking²⁵” in our later discussion on new directions, but many cases argue for a re-examination and improved understanding in terms of better meeting user knowledge needs.

Knowledge sharing and networking

Linked to the previous lessons learned, continued experimentation with new shared learning ideas such as knowledge platforms (see the European case study) and even more effective use of good old fashioned communications tools and networking (most of our case studies) are suggested.

²⁵ We coined the term aquaface (cf coalface) to highlight this line of new aquaculture thinking around knowledge translation and related practice and implementation thinking in aquaculture.

Knowledge management

Knowledge management (KM) as an overall process would benefit from a deeper examination (and likely its adaptation) using some of the new thinking around knowledge supply and demand, for instance examination of the use and suitable adaptation of ideas and processes from the health sector.

Strategic Influence and reaching the necessary target audiences

Aquaculture needs to consider more carefully, and perhaps draw on some of the new communications thinking (e.g. Santucci, 2005) and that of strategic influence (e.g. Creech and Willard, 2001) as our collective thinking progresses around sustainability. We note the importance of issues such as developing critically important relationships (see, for example, the thinking of Carolan, 2006) and the need to better engage with key decision-makers and other critically important audiences in this work.

Conclusions

Our review raises a number of questions around whether aquaculture as a sector is adequately and effectively examining/managing available knowledge, both within and across this and related sectors, for example, questions around the development of a better understanding of farmer knowledge, traditional knowledge or some of the new thinking in the social and information/communication sciences. Such KM examinations might usefully explore some of the barriers to an open (and often critically important) sharing of knowledge. Our Chile case study, for instance, raises a variety of questions about timely sharing of knowledge on disease among farms, as well as with the regulatory authority. Conflicting forces, here perhaps too much driven by perception of market advantage and short-term revenues, led to various forms of secrecy or even critical delays in such knowledge sharing. The result was an on-going series of major crises with costly impacts that continue to have major consequences for most stakeholders in terms of the development of this industry.

At a regional level, it is suggested that the NACA “regional organizational prototype” has paid significant knowledge and other shared learning dividends in facilitating aquaculture growth and sustainability in the Asia-Pacific (see the NACA case study). At the regional scale, for the coming decade, the newly formed Network of Aquaculture in the Americas and the related plans in Africa for redevelopment of similar knowledge-sharing mechanisms provide further future case material for continued examination and lesson learning within and between regions, regions in which aquaculture will continue to follow different but knowledge-linked paths. Work to date around various start-up interregional knowledge-sharing activities suggests a future set of activities for development of optimal knowledge networking globally.

As the Chile case study argues, investment in basic research is at all times very relevant, and governments should strengthen funding for this kind of research. However, more applied and focussed research is also needed, and some countries have found mechanisms to support this, in some cases through public-private partnerships. Such research is very relevant to the solution of very practical problems at the farm level, for example, the development of a needed vaccine or the production of a type of feed for larvae.

More fundamental knowledge questions related to whether aquaculture is meeting the needs of most of its stakeholders (linked to various questions around how such knowledge is being used), need more assessment and detailed examination. Is aquaculture adequately reaching out to various downstream users? Is use of the media taking the appropriate form? In our experience, there is a reluctance to engage around contentious issues such as shrimp and mangroves. Many of our challenges in reaching the goals of the Bangkok Declaration relate to appropriate messaging and reaching wider sets of audiences (who often have very different understandings of the issues). This messaging needs to be appropriately linked to relevant “good science”, for instance, and a wider set of lessons learned that will be critical to their changing the behaviours of targeted actors.

Finally, we feel that the science and the process of aquaculture development could learn a great deal from a comparative look at related Knowledge Management thinking in other sectors. For instance, the work in the health sector with a particular focus on the knowledge sharing and knowledge translation thinking (Schryer-Roy, 2005) has led to more effective use of knowledge management for policy change processes as well as its use in health practice. This greatly strengthened implementation of knowledge in terms of “on the ground” changes in aquaculture practice is highly desirable. As mentioned, we see major gaps in aquaculture work to date around what we are calling “aquaface thinking” (a term borrowed from work at the coal face), where KM strategies are strongly linked to this more and better understanding of working at the aquaface or implementation science.

In closing, we return to our opening quotations on knowledge networking and communications thinking and remind all that much of our knowledge will be increasingly stored in our partners, friends, colleagues and neighbours. Therefore, it is advisable to carefully plan and invest more in shared learning and perhaps just being neighbourly beyond the Phuket conference. It may be time to give more attention to being a good aquaculture neighbour!

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Servicing the aquaculture sector: role of state and private sectors

Expert Panel Review 5.2

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Abstract

This paper was prepared by a group of authors of complementary experiences and presented during the *Thematic Session V: Improving knowledge and information sharing, research and extension in aquaculture* at the Global Conference on Aquaculture 2010, *Farming the Waters for People and Food* held in Phuket, Thailand on 22–25 September 2010. The paper, which draws particularly on experiences in Asia, the Pacific and Europe, reviews the role of aquaculture services, recent changes in requirements and delivery of services, and future opportunities and needs, with special reference to roles and responsibilities of state and private sectors. It concludes with recommendations drawn from the discussions at the conference, where the importance of investment in services across the sector was emphasized, noting the particular significance of equitable service delivery to smaller aquaculture enterprises in developing countries, including emerging aquaculture countries in Africa.

KEY WORDS: *Aquaculture servicing, Role of state and private sectors.*

Background

This paper considers aquaculture services, and the role of the state and private sectors. According to the Organisation for Economic Co-operation and Development (OECD), the term “services” covers “*a heterogeneous range of intangible products and activities that are difficult to encapsulate within a simple definition. Services are also often difficult to separate from goods with which they may be associated in varying degrees*”¹. In aquaculture, such services encompass a range of different products and activities that can be broadly categorized, albeit with significant overlap, as follows:

- a) *Extension:* Systems of communication for knowledge transfer and skills development that traditionally have provided practitioners with access to the required knowledge and skills on technologies and systems for aquaculture planning and operation. The term extension systems is now being, or at least should be, considered more broadly, encompassing non-technical services such as marketing and business advice or more broadly, empowerment of farmers in decision-making and better management. This is in recognition of the fact that rural farmers face many diverse challenges that go considerably beyond purely technical considerations.
- b) *Financial:* Services that provide access to finance for aquaculture infrastructure or operations, and insurance products. Such services may be delivered in various ways, from microcredit to larger-scale investment schemes, and involve private and public sectors.
- c) *Market:* Information and other services related to market requirements, prices and facilitation of market access and communication between producers, buyers and consumers along the value chain.

¹ www.oecd.org/faq/0,3433,en_2649_34233_23183508_1_1_1_1,00.html

- d) *Business*: Business development services that may include all aspects of aquaculture from investment to planning, development and organization.
- e) *Input provision*: Services involved in provision of inputs needed for aquaculture, such as production and delivery of seed, feed and other material inputs.
- f) *Infrastructure and transport*: A wide range of services that facilitate supply of inputs, water, and transport of products to market. Often physical infrastructure itself is not necessarily developed specifically for aquaculture, such as roads, dykes, electricity or sluice gates, but may indirectly provide benefits for aquaculture farmers or contribute to aquaculture development.
- g) *Technical services*: Consultancy and other technical services for aquaculture development and management, including environmental studies and analytical services for water and soil quality, pathology, input and product contaminants and residues. Analytical services are becoming increasingly essential for food safety assurance and addressing World Trade Organization (WTO) sanitary and phytosanitary (SPS) and technical barriers to trade (TBT) issues in the aquaculture sector.
- h) *Harvest and postharvest processing*: This service category may involve assistance ranging from harvesting to access to seafood processing facilities provided either through product sales or service arrangements.
- i) *Research and development*: This category includes services involving generation of new knowledge, improvements and solutions to problems, ranging from on-farm, action-type research to higher-level strategic research and longer-term investments such as genetic improvement programmes.
- j) *Communication*: This includes services that encompass a wide range of communication activities providing knowledge on a wide range of topics, from general news on developments, markets, policies, legislation, etc. through various media, and more focused services, including recent initiatives with short message service (SMS) and other information and communications technology (ICT) programmes focused in specific localities. Communication services of course more generally support the other services mentioned above.
- a) *Governance and regulations*: Governance of aquaculture is receiving increasing attention, and likewise several countries have established services to support and regulate industry development. These may include, for example, the Coastal Aquaculture Authority (CAA) in India, which regulates the activities connected with coastal aquaculture in coastal areas of the country.

Why are services important for aquaculture?

Products and activities provided through such services are generally important from planning to operation of aquaculture enterprises, and throughout the whole “value chain” of aquaculture from input supplies, production through to marketing and consumption. They encompass the development of aquaculture in new

countries or regions, as well as improvements in efficiencies and technologies of established farming systems in existing aquaculture-producing countries. They are relevant, in various ways, for all types of aquaculture, from subsistence farming through the spectrum of aquaculture enterprises from micro and small-scale household-managed farms and businesses through to medium and large business. Broadly speaking, services in various forms have been and always will be an essential part of aquaculture development, and successful aquaculture development requires that the services needed are in place.

Who provides services and how are they delivered?

Public and private sectors, including non-government agencies, are involved in provision of various aquaculture services, although roles and responsibilities differ and indeed have changed significantly in recent years. For example, the traditional roles of government in extension services are now shifting towards a more private-sector “user pays” orientation, including, in some countries and regions, an increasing role of private-sector organizations and farmer associations (such as the Federation of European Aquaculture Producers (FEAP)), non-governmental organizations (NGOs) or public-private partnerships in service delivery. The emergence of large aquaculture companies in nearly all regions, including recently Africa, has also facilitated their own development of a range of services covering in some cases all categories listed, for their own operations but also for aquaculture suppliers and producers associated with them.

Services also operate at various levels, from the local community through to regional organizations and international levels. International or bilateral donors and development banks have helped facilitate growth by investment in services in some countries, particularly developing countries. The mix of responsibilities in services and their delivery can be summarized as follows:

- a) *Extension*: The public sector traditionally leads, but there is increasing private-sector involvement, albeit with an emphasis towards larger enterprises. NGOs may also be active through donor investment projects, but these often lack sustainability. At the local level, farmers’ organizations may play a role, through the development of farmer trainers, resource persons or other services. A key issue is sustaining farmer organizations requiring a steady income stream.
- b) *Financial*: The private sector is dominant, although services may involve public-sector investments in infrastructure or guarantees or other risk management measures. Development banks, both national and international, also play an important role. Governments may also establish special funds for aquaculture, such as the New Zealand Government “Sustainable Farming Fund”, which was recently opened to aquaculture². The “informal” private sector is widely involved, such as via credit provided

² www.maf.govt.nz/agriculture/funding-programmes/sustainable-farming-fund.aspx

by local traders, particularly in developing economies. Finance now flows easily across borders, and there are increasing international transboundary investments in aquaculture. Donors are also involved in various ways, but the trend is that donor projects should not be involved in sector-specific credit, rather they should facilitate the development of financial systems that provide benefits to a wider range of rural enterprises. Obtaining capital for aquaculture can be a formidable task for many aquaculturists (Pomeroy and Getchis, undated), and small-scale commercial aquaculture farms face particular difficulties in accessing finance in many countries.

- c) *Market*: The private sector dominates, although the public sector is involved to various extents, such as in infrastructure and knowledge transfer mechanisms, including intergovernmental agencies such as INFOFISH. This involvement may be through regulatory provisions, such as for traceability. The emergence of demand by retailers and large buyers of certified or “sustainably produced” aquaculture products has recently led to an increase in services provided by intermediaries connecting producers to buyers of higher-value produce, particularly for internationally traded products such as shrimp and catfish.
- d) *Business development services*: The private sector is dominant, although the public sector or donors may also assist in providing financial or other support to development of such services for rural communities, although this support is often tied to projects and may lack sustainability as a result.
- e) *Input provision*: The private sector dominates in providing access to the inputs needed for aquaculture, such as seed, feed, etc. The role of governments and increasingly, international agencies, is more in the setting and management of quality standards and in traceability.
- f) *Infrastructure and transport*: There is both public and private-sector involvement; government financing and policies may have a significant influence on infrastructure development.
- g) *Technical services*: The private sector dominates through independent businesses or linkages to large companies or groups of producers, but government agencies play an important role in some countries, especially with regard to environmental aspects or where there are social objectives, such as investing in technical services to small-scale farmers.
- h) *Research and development*: The public sector traditionally leads, but private-sector research and development (R&D) is becoming more significant as aquaculture grows, particularly among larger international businesses. Universities are also involved in R&D service provision. There is increasing recognition of the importance of involving farmers in “action research” type approaches.
- i) *Processing*: Usually, only the private sector is involved, but governments can facilitate or regulate arrangements between farmers and processors.
- j) *Information*: Both the public and private sector are involved in communication services, but the private sector is increasingly dominant. New social networking tools are also opening new avenues for knowledge transfer.

Government roles in all the above vary considerably from country to country and at various stages of the development process. Other related interventions from government may include subsidies, supporting minimum prices from time to time, or provision of tax incentives for investors in aquaculture. The influence of the government and the policy attention given to aquaculture, therefore, plays an important role in aquaculture development and also the ways in which private services develop.

How has the situation changed/improved over the past decade?

What are the major changes in type of and need for services?

Growth in aquaculture over the past ten years, influenced by a range of global drivers, has changed not only the nature of the services required but also the way in which these services are delivered. While this is generally true, it should be recognized that the services required by different socio-economic groups can be rather different, e.g. in extension modes, inputs supplies and credit modalities, and in the response and needs related to global drivers.

Global drivers that are influencing services include:

- the increasing demand for aquaculture products, driving growth, investment and in some countries, the increasing numbers of farmers engaged in aquaculture;
- consumer and retailer demands for “sustainable” and “safe” products, leading to the requirements for food safety assurance and certification;
- globalization trends that have eased the way for transnational investment and an increased flow of services and aquaculture products;
- integration of supply chains for seafood products; and
- major progress in Internet and other technologies facilitating communication.

In less-developed and newly emerging aquaculture countries, investment in basic services is still required to support growth of the sector, particularly if it is to deliver benefits that many countries and donors seek in improving the livelihoods of people living in rural societies. In others, market pressures, in particular the recent moves towards certification and food safety and quality assurance, have created new requirements for extension, business advice and technical services that can be provided by both the private and the public sectors.

While a wide range of services are needed to enable the growth and sustainability of aquaculture, equitable access to service remains uneven. Beyond subsistence farming, still found in some regions such as Africa, the micro and small aquaculture enterprises, largely involving households and operated as small-scale family businesses, involve large numbers of people, and remain socially and economically important to many rural communities, particularly in Asia but also in other regions. Such family-oriented enterprises

face increasing problems in participating equitably in some modern value chains for aquaculture products due to such factors as:

- costs associated with achieving efficiency of scale and establishing modern business structures;
- inequitable access to markets and market information;
- difficulties in access to financial and technical support services;
- environmental constraints; and
- increasingly high production standards, food safety and quality assurance requirements if farmers wish to engage in international markets, and increasingly more demanding domestic markets.

While rising domestic demands in many Asian countries and in Africa provide perhaps easier entry points for households to markets, services will also be required to achieve market access. Certification for access to both developing and developed markets risks excluding small-scale entrepreneurs from opportunities to improve livelihoods through aquaculture. Exclusion of smaller producers from export markets risks significant social and economic impacts in some rural and coastal communities across Asia. In Africa, growing recognition of the role of small and medium enterprises as a pathway for aquaculture growth will also require special attention to investment in services. In Europe, the concerns for the smaller farmers are identical to those elsewhere since, without certification, it is virtually impossible to supply the multiple retail stores, which are responsible for 85 percent of retail sales in northern Europe. In markets where food safety and consumer interests dominate, these positions are unlikely to reverse.

Equitable access to services for smaller aquaculture enterprises and household-level producers is a challenge in most developing countries. As a consequence of new market requirements and in order to support their aquaculture industries, governments have had or will need to invest in some basic services, in particular, surveillance and analytical capacity, such as for food safety assurance, and aquatic animal health management measures. There is, however, an evolving “aquaculture divide”, with many rural farmers, particularly in less developed countries, still having limited access to requisite aquaculture services. Nonetheless, it is observed that, at least, there is a growing awareness of the need for better services for the small-scale sector, and a direction for the future will be to look for service improvements that deliver the necessary support.

The small-scale sector needs different services from the conventional transfer of technology mode of extension and credit from formal credit institutions. There are large numbers of farmers in Asia that are not producing for the international market. Most of the improvements needed in the early stages of aquaculture development require basic skill levels, and do not need a degree in aquaculture to communicate such skills to farmers. Formal government services commonly do not extend beyond a few kilometers of district centers in many countries, and

thus there is a need for a system to bridge the gap down to the field level, and here there is increasing recognition that farmer organizations can play a role.

What are the major changes in delivery of services?

Essentially, the aquaculture sector lags behind the agriculture sector in development of many support services, particularly in rural areas of developing countries, and indeed there are still many significant gaps. Nevertheless, we can see some major changes in the way that services are being delivered in aquaculture, and opportunities, particularly with the rising role of communication technologies and Internet. There is also a rising capacity in Asia for management of the sector and delivery of services both in the public and private sectors. Within Europe, on-line sales and traceability services are providing new means for distance selling but evidently require adaptation of the way in which sales and marketing are viewed by the operator.

Market requirements and the increased frequency of occurrence and diversity of aquatic animal pathogens have increased the need for both the public and the private sector to develop technical and analytical services in order to guarantee the health of cultivated animals and the safety of the products.

What are the major changes in the role of government and private sectors?

In many countries, the government role in extension services has reduced during the past ten years, while the role of private business has increased. Public and private services available (e.g. government extension systems, private feed and pharmaceutical companies) tend, however, to be oriented towards the larger enterprises and currently do not adequately support the smaller-scale enterprises and farmers, let alone provide a mechanism for improvement. This is partly because small-scale farmers are considered “difficult” and often because the necessary skills and investment required for the service envisaged are not available or well targeted. In the agriculture sector, the business opportunities among many millions of small-scale rural farmers have been recognized – through such classics as Prahalad’s *The fortune at the bottom of the pyramid* (Prahalad, 2006) – and products and services oriented towards small-scale rural consumers. There is a need for business models of services for smaller-scale aquaculture farmers, perhaps in cooperation with smallholder-oriented agriculture or other rural services.

Within Europe, private-sector networks (usually within associative structures) provide information and related support services, which can include generic marketing actions. These structures also provide the link of the sector to government, enabling needs identification and the manner in which essential services can be provided. Nonetheless, the key suppliers have developed their own capacity to be able to provide valuable on-farm services.

Globally, but mostly in North America and Europe, governments originally invested in developing the aquaculture technology that is now used by the private sector and continuously improved mostly by well-financed, large companies. Now governments focus their efforts more on research and surveillance programmes to ensure a sustainable future to the aquaculture industry.

Some examples and lessons learned

Projects across Asia are starting to show that providing access to simple skills and technologies can make significant differences to small-scale aquaculture households and small and medium aquaculture enterprises. Experiences of a number of agencies in Bangladesh, India, Indonesia, Thailand and Viet Nam have demonstrated that the adoption of simple management improvements and organized collective improvements, such as self-help groups, can reduce costs, reduce the risks of disease outbreaks, reduce environmental impacts, improve profits and provide better livelihoods³. The challenge in moving forward is not to continue to replicate such “pockets of success”, but to leverage such local successes to scale up such experiences across a wider swathe of aquaculture farmers and small and medium enterprises (SMEs) in Asia (Umesh *et al.*, 2009).

Seafood safety issues and bans from importing countries resulted in several governments imposing new regulations and controls to the aquaculture industry, which seems to contribute in great measure to the sustainability of the activity through improved management and environmental awareness. In that sense, markets have also played an important role in creating the need for improved services to the aquaculture industry. Selected experiences are provided below.

Bangladesh – Danida experiences

Danish International Development Agency (Danida) projects in Bangladesh have emphasized development of local services, and used a farmer field school (FFS) approach in extension. FFS has been used to help farmers to analyze their own situation and share experiences to effect low-cost improvements in their existing systems. The FFS are facilitated by young people from the local community trained by the Danida technical assistance project in how to conduct such FFS and in the options for technical improvement. On this basis, it appears that household earnings from aquaculture can be significantly increased in a short time through basic improvements in aquaculture farm management and technologies. Training is supported by service provision by farmer organizations. Sustaining such services will require investment by government, but also business models that can generate income for services.

³ As an example, investment in technical services of USD66 000 led to increased profits for 700 small-scale Indian shrimp farmers of around USD1.4 million in 2006 (Umesh *et al.*, 2009).

India – NaCSA experiences

Public and private sectors both have important roles in the India National Center for Sustainable Aquaculture (NaCSA) model. No one sector can completely fulfill the needs of small-scale farmers. Most small aquaculture farms in India lack basic infrastructure facilities like roads, bridges, electricity and other requirements, in common with many other farmers in poor rural areas. The public sector can play an important role in developing infrastructure facilities and empowering small farmers by providing information and training which are basic needs. The reason most governments are lacking in aquaculture service compared to agriculture is that aquaculture is of recent development and there is a lack of information on the potential role the sector and its ancillary industries play in rural development. Lessons learned in NaCSA (Umesh *et al.*, 2009) are.

- Government can play a key role in development of infrastructure facilities for small-scale aquaculture and assisting in with finance. The Indian Government recently has come up with financial support for infrastructure development (electricity, roads and bridges) and is also writing off 50 percent of the premium on insurance for small-scale aquaculture. This was made possible through the registration of nearly 20 000 small farmers (25 percent) with the government in the last two years, which was facilitated by NaCSA.
- Providing information/training to small farmer groups empowers farmers to make appropriate decisions and solve their common problems.
- Simple management improvements through organized farmer groups can reduce costs, reduce risks of shrimp disease outbreaks, reduce environmental impacts, improve profits and provide better livelihoods.
- Better infrastructure facilities will enhance implementation of better practices and help to improve productivity.
- Better market prices encourage farmers to invest in better farming practices.
- Business-oriented private-sector service tends to focus on large-scale farmers for economy of scale, with small farmers often being ignored. Services are often provided by feed and chemical suppliers mainly to promote their business interests.
- Procuring good quality seed is still a major challenge for small farmers and is critical for the success of their operations.
- Organizing farmers also encourages entrepreneurship. Farmer groups have come forward to start their own hatchery to cater to their own demand for quality seed.
- Small farmers are resilient; with better service provision their living standards can be further improved.

Seafood Services Australia

Seafood Services Australia (SSA, www.seafood.net.au) is a not for profit company established in 2001 and supported by the Australian seafood industry and the Australian Government through funding from the Fisheries Research and Development Corporation. The goal of SSA is to enhance the

profitability, international competitiveness, sustainability and resilience of the Australian seafood industry. As the domestic and global markets become ever more complex and sophisticated, the competitiveness of Australian seafood businesses is being challenged. These challenges are beyond the capacity of individual businesses to address. SSA works with seafood industry people and extensive networks and alliances across industry and government to improve industry practices and to capitalize on opportunities that would not otherwise be realized. The service helps create the incentives and tools for the industry to act as a united seafood industry, to build an environment in which individual businesses can be more profitable and sustainable. Priorities are:

- trade and market access;
- cost of regulatory compliance;
- environmental accreditation;
- strategic alliances; and
- cost of production.

The programme is guided by the SSA Business Plan (SSA, 2007), and programmes are developed with extensive stakeholder input. The four programme areas are (1) Security of Supply; (2) Security of Markets; (3) Product Integrity and Standards; and (4) Knowledge Broker.

Have the expectations and commitments expressed in the bangkok declaration been met?

The Bangkok Declaration does not refer specifically to services as such, but services are directly and indirectly referred to in various elements of the *Strategy for Aquaculture Development Beyond 2000* (NACA/FAO, 2000) as noted in Box 1. In general, there has been progress in many aspects of service provision; however it is questionable whether “improving the capacity of institutions to

BOX 1. Relevant elements of the Bangkok Strategy for Aquaculture Development Beyond 2000

- 3.1 Investing in people through education and training – the importance of education and training services
- 3.2 Investing in research and development
- 3.3 Improving information flow
- 3.4 Improving food security and alleviating poverty – where the emphasis of services is noted to deliver support among poorer groups involved with aquaculture
- 3.7 Investing in aquaculture – where the importance of investment and credit is noted, including micro-finance for smaller-scale producers
- 3.8 Strengthening of institutional capacity
- 3.9 Managing aquatic animal health – includes reference to improvement in services
- 3.10 Improving food safety and quality
- 3.11 Promoting market development and trade – which includes reference to market access

develop and implement strategies targeting poor people” has improved or approaches tried have been effective. This aspect remains a key challenge for the future. Focus in improving institutional capacity has perhaps been too focused on central governments and their officers at the local level and not enough upon local government and other local organizations.

What are the future expectations?

The future growth of aquaculture requires that the services needed are in place, with roles and responsibilities for public and private sectors. It will also need strengthening of partnerships among various actors to ensure services are delivered effectively and respond to needs. These needs include not only those of producers, but those of the whole value chain. Actual requirements will depend on the growth and future scenarios, as well as regional and country differences, but there are several major complementary directions for the future:

- improving access to services that deliver to larger number of farmers, particularly in developing countries;
- increasing the quality of services to respond to current and future needs for all enterprises;
- adopting a more collaborative approach, with different partners bringing complementary skills and resources to deliver the services required; and
- taking a value-chain and more business-oriented approach that takes account of all aspects of aquaculture production through to market.

Such approaches will require new investments and in some cases new policies, tools and infrastructure interventions (e.g. see agriculture approaches in the World Economic Forum, 2010). Analysis of national aquaculture strategies and existing services, and stakeholder consultations can be a starting point for reforms and investment in better services.

In Europe, the family farm and smaller enterprises face many of the same difficulties reported in Asia: access to markets, lack of economies of scale, requirements for new skills and others. This has led to buy-outs and consolidation of different components of the sector, so while production does not reduce, the number of separate enterprises does through consolidation. This leads inevitably to an increasing divide between the larger companies and smaller-scale farming activities. Assuring the survival of the smaller aquaculture entities will be based on the assurance of access to the services described and also the manner in which they can access the markets that is required for their capacity to continue their activity. Inevitably, this means either focusing on local markets or grouping within structures that will enable access to larger national or international markets.

In Asia, a major challenge remains to improve the access to services for many smaller-scale aquaculture enterprises. Experiences in Asia in addressing such

issues have shown that short-term technical assistance projects can achieve good success with helping farmers to organize self-help groups and adopt better management practices (BMPs); however, sustaining achievements beyond an individual project cannot be done effectively without more attention to creating sustainable, business-oriented institutions. New approaches are needed in the way that technical, financial and market services are organized and delivered to farmers; where governments have been dominant in extension in the past, with mixed results, there is a need to shift attention to more business-oriented servicing solutions, networked for economies of scale and knowledge sharing, if small-scale farmers and communities are to be an important part of future aquaculture growth. New technologies, such as spread of the Internet and mobile phone service through many rural areas may also offer many opportunities for provision of necessary services in a more cost-effective manner, taking account of efficiencies of scale.

Farmer organizations may need to play a more important role (Kassam, Subasinghe and Phillips, 2011). Such organizations should more than recover costs for their services in order to become financially sustainable. Arguably, they should be offered grants as a start to making the necessary economic investments and developing the financial strength to make them “bankable” in the sense of borrowing from the commercial sector.

An issue here is whether such institutions can be dependent on a single sector. Most small farmers are not specialists and need services in crops, livestock and even handicraft supplies, not just aquaculture. Such organizations need to make links with local, subregional and national suppliers of quality inputs and with markets. To be effective in bargaining/negotiation, this will often involve associations or federations of grassroots organizations. Without further investment in new approaches to service delivery, the small-scale enterprise pathway for future growth of aquaculture will be far from assured. Research is needed on producer companies, cooperative arrangements, contract farming and other more socially oriented enterprise models to design and support appropriate sustainable approaches (e.g. Prahalad (2006), and experiences from the agriculture sector, such as Anon. (2005)).

Panel recommendations

The following recommendations were developed by the panel and further discussed during the Phuket conference:

- A wide range of services are essential for future growth of the aquaculture sector. There are many good initiatives, but the challenge is delivering the right combination of services to users, ensuring equitable access and creating impact at scale, particularly to large numbers of small-scale producers. New technologies, non-conventional approaches and new investments are required.

- The state and private sectors both have roles to play. Appropriate roles and responsibilities of the public and private sectors in providing aquaculture services should be clearly defined in participatory policies, strategies and plans, to foster private-sector led approaches wherever possible, to identify any market failures that require public-sector responsibility for provision of services, and to avoid competition and increase complementarities between public and private services delivery.
- There is no “one size fits all” model, but there is a need for sharing and networking of experiences to work at scale.
- Farmer organizations and local institutions that support such organizations and provide services require special attention.
- Small-scale farmer groups and clusters should be promoted wherever there are small-scale aquaculture farmers. Cluster formation should be a part of government policy as a development activity to assist small-scale farmers. Setting up incentive structures and creating reward and support systems that motivate farmers to scale up such programmes are required. Groups and clusters should be formalized or registered as a group for accountability. Training tools should be developed to assist government, NGOs and private service providers in forming clusters, taking in to account existing experiences.
- Success stories should be widely publicized to inspire national and local-level efforts to promote formation of farmer groups.
- Broad stakeholder networks, including farmers and their organizations must be created. Effort must be made to bring together federations of farmer groups in different countries to create economies of scale and social capital to increase bargaining power.
- Public services cannot be sustained indefinitely, and appropriate business models for services should be explored and promoted, including in rural areas and using models that work for small-scale farmers. Private-sector investment should be encouraged in models that work for small farmers.
- Extension service by private companies must be encouraged and general guidelines have to be laid out to ensure a responsible approach. Business models that support farmer groups, local servicing systems and networks, and deliver services to small-scale rural farmers should be developed.
- Investment in services can be guided by creating a strategic plan for services in each area/region. A strategic plan for services could then be used as a guide to all aspects of services, including funding by various investors into the future. From that knowledge, actions could be taken based on needs. To support this, there is a need for (1) a list of all services and what they do in each country (Priority should be on countries that are considered poor and working upwards. This enables looking at gaps and communication hubs or assists in creating collaboration across the services already in place); (2) a list of all examples, and small case studies done on a few to give people examples of what can be achieved; and (3) a prioritized list of services that need to be created in each area/region filtering down to countries.

- Small farmers are a diffuse target and servicing them adequately is often too demanding for governments with limited financial resources and profit-oriented commercial partners. There is an urgent need for small farmers to cluster so they can be viewed and supported as organizations, which in turn would have the capacity to develop some internal services to their members as a complement to external support.
- New market and certification requirements are a challenge, but also an opportunity to introduce changes in the organization of the aquaculture industry, and in particular improve services to small farmers.
- There is a need for investment in scaling up existing projects that have potential to becoming self-sustaining enterprises.
- There is a need to build coalitions among investors to ensure the necessary services are provided.
- Africa is emerging as a strong region for future aquaculture development, and further attention is required on the services needed to develop and sustain the growth of aquaculture within the continent. Lessons learned from other regions may provide useful guidance, but ultimately investment in and the growth of strong indigenous services will be necessary. Further analysis of requirements would be useful in assessing future servicing needs and strategies.

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Progressing aquaculture through virtual technology and decision-support tools for novel management

Expert Panel Review 5.3

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Abstract

Attention is presently turning to the processes, methods and tools that allow the principles of the ecosystem approach to aquaculture to be translated into practical implementation. An essential element for this is the use of virtual technology and decision-support tools, particularly if developing nations are to implement the key elements of aquaculture sustainability. We provide an overview of current and emerging issues and trends related to this topic over the past decade, an assessment of progress with regard to the expectations and commitments expressed in the Bangkok Declaration and conclude with some thoughts for the future.

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Virtual technology is the means by which conceptual models can be made more formal and tested against reality. It involves the collection of data, the integration of these data within a system (information system), the formalization of the system and the action on the system (simulation) with a given purpose. In this review, we therefore address two different types of tools: (a) modelling tools (the way by which information is used for a given purpose—modelling is used here in a very broad sense) and the link to data collection technology, and (b) tools which allow measurements to be made and translate data into information (information and communications technology).

Natural resource managers, aquaculturists and other stakeholders, pose questions on water quality diagnosis, growth and system carrying capacity and environmental effects, local-scale interactions, prediction of harmful algal blooms, disease control systems, environmental product certification, socio-economic optimization, spatial definition of natural and human components of ecosystems and of competing, conflicting and complementary uses of land and water. Many of these can be addressed, at least in part, by means of virtual technologies and decision-support tools.

The data needed for management and decision-making are similar across most aquaculture operations. However, the space and time resolution of the data sets are dependent on the scale of the aquaculture operation, and depend also on whether it is a single managed entity or an aggregation of independently managed entities. Consequently, the data acquisition approaches and needs expand with the scale of the aquaculture operation, and become a system-scale requirement when placed in the context of spatial planning, ecosystem-scale carrying capacity assessment, and integrated coastal zone management (ICZM).

Examples of key applications focusing on specific issues are provided, and contextualized by means of case studies, addressing a range of culture types and cultivated species; these consider aquaculture sustainability at both the system-scale and farm-scale, deal with open water and land-based pond culture, and with forecasting at the scale of the cultivation cycle and real-time evaluation of animal welfare.

The main constraints in the application of virtual technology in developing countries are identified, together with potential ways to address such problems. Virtual technology and decision-support tools will play an important role in addressing many elements of the *Bangkok Declaration and Strategy*. Some of the directions and challenges are: innovations that will drive virtual technology, information exchange and networking, links between industry and research centers, collaboration between developed and developing countries, strategic alliances in developing countries, and making virtual technology tools more production and management-oriented. Even if attractive and promising, these

tools will have to be adapted to local realities and conditions to really become useful (and used) in the future. This requires a compromise with respect to ease of use, data requirements and scientific complexity. A few of the gaps identified in this review are: disease and harmful algal bloom modelling, use of models for certification and traceability, and modelling with data scarcity.

In the future, virtual technologies will play an increasingly important role in the planning of potential aquaculture siting and production, environmental impacts and sustainability. The next decade will bring about major breakthroughs in key areas such as disease-related modelling, and witness a much broader use of virtual technology for improving and promoting sustainable aquaculture in many parts of the world.

KEY WORDS: *Aquaculture, Decision-support, Geographic information systems, Internet, Management, Models, Remote sensing, Virtual technology.*

Introduction

Background

Attention is presently turning to the processes, methods and tools that allow the ecosystem approach to aquaculture (EAA) principles¹ to be translated into practice. The EAA is the current framework being implemented by the Food and Agriculture Organization of the United Nations (FAO) and is defined as a strategy for the integration of aquaculture within the wider ecosystem in such a way that it promotes sustainable development, equity and resilience of interlinked social and ecological systems (Soto, Aguilar-Manjarrez and Hishamunda, 2008; FAO, 2010).

The implementation of EAA requires the use of a range of methodologies and tools, including environmental impact assessment (EIA) and risk analysis. An essential element for the implementation of EAA will be the use of virtual technology and decision-support tools, particularly if developing nations are to promote the key elements of sustainability and environmental balance as they increase healthy food supply and food security for the population by means of aquaculture.

¹ The FAO proceedings *Building an Ecosystem Approach to Aquaculture* present the output of an expert workshop organized by FAO and the Universitat de les Balears from 7–11 May 2007 in Palma de Mallorca, Spain. It includes contributed papers on definitions, principles, scales and management measures, human dimensions, economic implications and legal implications that are relevant for an ecosystem-based management in aquaculture. The workshop participants agreed that the EAA should be guided by three main principles that should ensure the contribution of aquaculture to sustainable development: i) aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity; ii) aquaculture should improve human wellbeing and equity for all relevant stakeholders; and iii) aquaculture should be developed in the context of (and integrated to) other relevant sectors (Soto, Aguilar-Manjarrez and Hishamunda, 2008).

Like any economic activity based on finite natural resources, aquaculture is sustainable if its limits in terms of social and environmental costs can be determined, and that information applied for financial return drove development in aquaculture (35 years ago). There was little knowledge or consideration of negative environmental or other impacts in many areas. Large-scale destruction of mangrove habitat in shrimp farming was commonplace, while severe benthic enrichment under salmon cages was another widespread consequence (FAO, 2009). The pace of development, inadequate regulation, and lack of field data and management approaches led to the lingering negative impression of aquaculture that persists today in many areas. Public awareness of the term sustainability has allowed it to enter into common lexicon as a synonym for “environmentally aware”, a total simplification of its meaning. Notwithstanding, the term sustainability is difficult to define because it has so many dimensions, including culture, recreation, economics and ecology. In the broadest context of all of these criteria, a general definition of environmental sustainability would be that ecosystem goods and services are not compromised by a given activity.²

Issues of sustainability in aquaculture require a consideration of goals and endpoints (i.e. criteria for acceptable impacts), as well as rigorous tools to define these categories. There is diversity in these endpoints, including both economic (e.g. acceptable product size, quality, cost) and ecological (e.g. organic enrichment) criteria. These issues are tied into spatial scales; such scales can be defined, in engineering terminology, as near-field, i.e. in the vicinity of a production site, or far-field, i.e. a broader area, several kilometers from a farm. For example, reduced product quality from overcrowded stocking is an issue more restricted to the area of the farm. Likewise, tourism is not compromised at large distances from farm locations. However, ecological sustainability is linked to the far-field, a typically poorly understood aspect of aquaculture impacts. Research in this area is receiving increasing attention, particularly due to risk of farmed salmon impacts on wild stocks. Far-field impacts on aquaculture farms, such as the offshore development of harmful algal blooms (HAB) and advection to cultivation areas are an additional consideration with both economic and public health effects.

At such broader spatial scales, one is then faced with answering questions about assimilative capacity and indicators of ecosystem health. For this reason, sustainability is closely associated with concepts of ecosystem-based management (EBM) and EAA. The real value of assigning metrics to evaluate indicators exists both in managing existing culture and in the development of new ventures. The guiding principle is that sustainability is easier to plan than it is to retrofit. In this case, retrospective analysis using models is invaluable, and its inclusion in a decision support system imperative.

² See also FAO standard definition of environmental sustainability: according to Brugère *et al.* (2009) Environmental concerns oblige aquaculture policy-makers to assess environmental risks in their planning.

Despite a rather loose framework, the following questions can be posed:

- What is the role of ecosystem modelling in predicting the development of sustainable aquaculture projects?
- How can sustainability be delivered as “advice” to regulators and/or coastal communities?
- What is the scope of solutions to be gained from culture practices such as Integrated Multi-Trophic Aquaculture (IMTA) versus technological advances (e.g. monitoring)?
- How can the specifics of aquaculture be integrated into tools for the assessment of broader coastal sustainability?

Throughout this review, these questions are kept in mind whenever possible, particularly with respect to the choice of case studies illustrating the application of virtual technology.

Review objectives

The Bangkok Declaration (NACA/FAO, 2000) aims to ensure the sustainable development of aquaculture over a ten-year horizon. It is clear that virtual technologies and decision-support tools are directly related to a number of strategic elements referred to in the declaration, such as: applying innovations in aquaculture; investing in research and development; and improving information flow and communication.

We provide an overview of current and emerging issues and trends about virtual technology over the past decade, an assessment of progress with regard to the expectations and commitments expressed in the Bangkok Declaration and conclude with some thoughts for the future.

This thematic review focuses on the following topics:

- *sustainable development of aquaculture*, both in qualitative and quantitative terms – indices of sustainability provide metrics which may be goal-functions of virtual management tools;
- *data acquisition and its relationship with the virtual world* – virtual technologies are of little use without robust underlying data;
- *types and objectives of virtual technology* – focusing on the technologies and what they can and cannot solve;
- *the path from technology to decision-support tools* – with real-world examples of outputs and outcomes; and
- *novel management approaches* – which leverage existing virtual technologies and tools to improve the socio-economic and ecological impacts of aquaculture.

Note: The impact of aquaculture on the environment is mixed, with aquaculture offering relief to overexploited fish stocks while causing long-lasting changes and detrimental impacts on the environment.

Virtual technology and decision-support tools

Definitions and characteristics of virtual technology and decision-support tools

Virtual technology has a fuzzy definition based on the representation of real-life systems by modern technologies. The closest definition can be found in Wikipedia for “Virtual Reality” – a technology which allows a user to interact with a computer-simulated environment, whether that environment is a simulation of the real world or an imaginary world. Therefore, all technologies which allow the construction of an artificial representation of the world and a “player” to interact with this artificial world fall within the definition of virtual technology.

Virtual technology – definition and scope

For the purpose of this review, virtual technology is defined as any artificial representation of ecosystems including the human element as recommended by the Ecosystem Approaches (EAs). Such representations, exemplified by mathematical models, are designed to help map, measure, understand, and predict the underlying variables and processes, in order to inform an ecosystem approach to aquaculture (EAA).

Representation of reality coincides with the modelling vocabulary. Models can be a conceptual view of the world which depends on culture, language, senses (sight, hearing, etc.), and are always a simplification of reality that is built with a given purpose. All models seek to optimize a trade-off among generality, realism, accuracy and simplicity.

Virtual technology is thus the means by which conceptual models can be made more formal and tested against reality. It involves the collection of data, the integration of these data within a system (information system), the formalization of the system and the action on the system (simulation) with a given purpose. We will therefore distinguish between two different types of tools, both of which are addressed in this review:

- tools which allow measurements to be made and translate data into information (information and communications technology, ICT); and
- modelling tools (the way by which information is used for a given purpose – modelling is used here in a very broad sense) and the link to data collection technology.

Since virtual technology is typically driven by one or more specific objectives, we will review the existing applications of virtual technology in the field of management of living resources (which directly links to aquaculture), with a focus on the specific issues addressed.

Stakeholder groups

We focus on the key questions asked by natural resource managers, aquaculturists and other stakeholders, and contextualize these with respect to

virtual technologies and decision-support tools. These questions include water quality diagnosis, growth and system carrying capacity and environmental effects, local-scale interactions, prediction of harmful algal blooms, disease control systems, environmental product certification, socio-economic optimization, spatial definition of natural and human components of ecosystems and of competing, conflicting and complementary uses of land and water.

Different stakeholders respond to these questions at differing time and space scales; for instance, an environmental manager for an estuary or coastal bay might be interested in system-scale carrying capacity, both in terms of production and environmental impact, while at the level of integrated coastal zone management (ICZM), the role of bottom-up (e.g. nutrient-related) effects and top-down (e.g. shellfish grazing) control might be an important consideration. Farmers will be more concerned with optimizing production and profit, disease control and market acceptance. Farmers and managers in the west may be more focused on open coastal systems, whereas in Asia, Central and South America, or in Africa substantial emphasis is placed on inland or fringing systems such as shrimp and/or fish pond culture.

An important third group of stakeholders are coastal residents and community groups. When they are engaged in scientific endeavours, it is beneficial to the entire process. In particular, communities are empowered to enter the decision process, especially when involved in the data collection aspects. Moreover, they have an inherent interest in the broader spatial scale, being concerned about more than just the local areas of aquaculture activity. In this context it is worth noting that there are key cultural differences in community approaches to coastline use; for instance in many areas of the United States of America and Europe, shorefront use is seen as primarily recreational, whereas in many parts of Asia there is a more utilitarian approach with respect to multiple uses, including cultivation of marine species.

Major issues and trends during the past decade

The recent literature shows a marked increase in the number of papers (from 300 in the 1990s to 1 400 in 2009) dealing with the management of aquaculture, based on a keyword search for “aquaculture” and “management” on <http://sciencedirect.com>.

The response of the academic community was driven by the rapid increase in aquaculture activities in the last ten years, which in turn has generated and/or increased the public awareness of the environmental impact of aquaculture and emphasized the risks of improperly managed aquaculture products to human health. Still, there is much public ignorance on aquaculture impact. Irrespective of whether inaccurate information is generated deliberately to promote a specific cause or inadvertently through ignorance, it can have a major impact on public opinion and policy-making.

Even though it is very difficult to identify general trends, concerns about environmental consequences and competition for resources, such as the “fishmeal trap”, have led to:

- complex site selection protocols, based on an integrated assessment which includes the estimation of assimilative capacity of environment, for finfish, and of carrying capacity, for shellfish, as well as the potential benefits and disadvantages due to conflict of uses with other activities such as fisheries, tourism and navigation, in particular for nearshore sites;
- management practices which tend to minimize emission of organic matter;
- feeding regimes which minimize use of trash fish, fish oil and fishmeal in feed by substitution from terrestrial sources;
- concern, at least within the salmon industry, on interaction with/impact on wild stocks. “Escape security” is a major issue in farm-scale management in order to reduce the risk of genetic impact from farmed salmon;
- impact of exotics imported for cultivation on the distribution of native species (e.g. the spread of the giant cupped oyster (*Crassostrea gigas*) in the Zeeland area of the southern Netherlands). This takes on particular importance in the light of climate change, due to biogeographical shifts in reproductive limits;
- design and application of monitoring programmes aimed at ensuring both compliance with environmental legislation and optimization of husbandry operations; and
- adoption of marketing strategies and market-led environmental management based on product traceability and ecolabelling.

In mature industries, such as salmon culture, these changes, which bring about additional costs, are causing a shift from independent medium-scale fish farms to multinational mariculture enterprises (Grøttum and Beveridge, 2007), which can successfully compete by reducing the costs through economies of scale, increasing the size and efficiency of production units. This trend is likely to be followed by other emerging aquaculture industries, as long as the sectors grow and the competition intensifies.

Several papers (e.g. Soto *et al.*, 2008) emphasize the role of spatial scales in aquaculture, but it should be noted that the distinction between feed-based and organic extractive cultures is important for identifying the set of virtual management tools which might best be applied, because the set of environmental services required is markedly different in the two cases.

Virtual technologies are already playing a major role in the transition of aquaculture towards a mature industry, as illustrated in our section on case studies, and their importance is likely to increase with the further development of IMTA, which is regarded as a promising means of enhancing sustainability and efficiency, in particular of cage culture (Tacon and Halwart, 2007).

Aquaculture management

Aquaculture management can be viewed from various perspectives (Ferreira *et al.*, 2008a), including: (i) insertion within the context of ICZM; (ii) the regulatory approach for granting licenses at the ecosystem scale; (iii) licensing of individual farms and monitoring of activities; and (iv) farm-scale management by the operators. In all of these cases, virtual technologies have an important role to play, be it through the use of (i) geographic information systems (GIS), remote sensing and ecosystem-scale models to determine suitability and carrying capacity; (ii) farm-scale tools to support licensing, environmental impact assessment (EIA) and optimization of production; or (iii) sensors for data acquisition for monitoring and modelling.

Marine spatial planning is another area where aquaculture management and virtual technology interact, through the use of GIS and other tools for harmonizing multiple uses of marine ecosystems. Aquaculture management can greatly profit from an ecosystem-based approach, combining scales and issues to promote sustainable activities. In itself, this kind of ecosystem approach is essential for ICZM, which forms the paradigm for water management in many parts of the world (e.g. Hovik and Stokke, 2007; Borja *et al.*, 2008; Nobre and Ferreira, 2009). European examples include the River Basin Management Plans required by the European Union (EU) Water Framework Directive (WFD) (EC, 2000), the holistic combination of descriptors, including e.g. biodiversity, sea floor integrity, food webs and eutrophication in the EU Marine Strategy Framework Directive (MSFD) (EC, 2008), and the impact model of five environmental aspects in the Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry from the Norwegian Ministry of Fisheries and Coastal Affairs (2009).

Figure 1 illustrates an example of a decision support system titled MarGIS™; it is a near real-time interactive software application, tailored specifically for

FIGURE 1
Layout of oyster trestles in Dungarvan Harbour, Ireland, showing a geographic information systems (GIS) overlay, colour-coded for different cohorts of cultivated animals



Source:
Dallaghan
(2009).

shellfish growers around the Irish coast, which will enable them to optimize their operations and production in a sustainable and environmentally sensitive manner. By using near real-time current conditions, MarGIS™ will allow a farmer to quickly see what effect on his productivity would be expected if he were to make stocking density changes, for example, or to reposition one or all of his mussel lines, or introduce more mussel lines in the vicinity of the existing farm. By allowing the optimization of husbandry techniques such as this, the software encourages farmers and communities to work together.

Scales

Spatial and temporal changes in the natural and human context raise issues for aquaculture (e.g. impacts on the environment, social and economic changes) but also provide frameworks for problem solving once the scale issues have been defined. EAA, the current framework being implemented by the FAO (Soto, Aguilar-Manjarrez and Hishamunda, 2008; FAO, 2010), provides guidelines for integrating aquaculture into the natural and human environments as well as for defining future goals for aquaculture development and management.

The objective of this section is to summarize experience in applying GIS, remote sensing and mapping to spatial and temporal issues in aquaculture. The geographic perspective is global. The material comes mainly from a review on spatial tools, decision-making and modelling in aquaculture by Kapetsky, Aguilar-Manjarrez and Soto (2010).

Spatial scales

Experts at the FAO Workshop on “Building an Ecosystem Approach to Aquaculture” (Soto, Aguilar-Manjarrez and Hishamunda, 2008) identified three scales/levels of EAA application: the farm, the waterbody and the global market-trade scale. Detailed definitions and examples of the EAA scales are now available as general guidelines (FAO, 2010).

Preceding the development of the EAA scales and based on the GISFish Aquaculture Database (www.fao.org/fishery/gisfish), Kapetsky, Aguilar-Manjarrez and Soto (2010) classified GIS applications according to stated or implicit scales among inland, brackishwater and marine environments. Seven scales were recognized among 159 applications in these environments, based on administrative divisions (i.e. local, state/province, region, country, multicountry region, continental, global).

Although one could consider spatial scales over a wide range, in the context of virtual technologies, it is most useful to address those relevant to potential ecosystem interactions, namely from farm to bay scale. Management decisions made at larger scales such as watersheds better address the EAA and can greatly benefit from the use of GIS tools. These approaches are contained within the broader concepts of marine spatial planning or zoning (Douve, 2008;

Klein *et al.*, 2009). In terms of the EAA scales, GIS applications applied to the farm and the waterbody were among the most numerous. This is unsurprising because most issues and most spatial applications to address them are expected to be at those scales.

Since spatial analyses can be applied at any scale (e.g. EAA, other frameworks), the appropriate scale can be defined by the geographic scope of the problem when expressed in ecosystem, administrative, social and economic terms. Spatial analysis and GIS-based tools principally aim to help us understand combined information at/from different scales, and are in that sense independent of scale. A good example could be an integrated watershed management scheme to combine agriculture, aquaculture and irrigation at different scales and watershed boundaries.

In practice, there is lack of experience using spatial tools in aquaculture when dealing with social scales – stakeholders at all levels – and to a lesser extent with economic scales. This can be addressed to some extent by scenario building with interactive GIS applications such as Marxan (Watts *et al.*, 2009).

Temporal scales

The temporal scales of interest for spatial analyses, like the spatial scales, are those defined by the problem, in this case, the duration of the issue or impact. In addition, the frequency of particular phenomena (e.g. HAB or El Niño) may be a conditioning factor. Three types of temporal scales may be recognized (Table 1).

TABLE 1
Summary of temporal scales of interest for spatial analysis

Temporal scales	Description
Natural	Changes in environment-aquaculture interactions over a range of seconds to millennia, but practically encompassing the economic life of aquaculture as a species-culture system
Socio-economic	The range of time that aquaculture is socially and economically viable, which can range from the earliest planning to the end of the business or programme, years to decades
Administrative	The range of time during which local traditions and/or legislation affects aquaculture, years to decades

Prediction is the objective underlying nearly all spatial analyses. Within the temporal scale of the problem are the limits imposed by the quality and quantity of historical data and the availability or utility of models and decision-support tools. An analysis of temporal scales was not included as part of the Soto, *et al.* (2008) review; however, it can be stated that most studies are “snapshots” in that the results, whether cast in the past, present or future, are for one or a few instances in time, even though they may be based on long series of environmental data. Real-time environmental forecasting in support of

daily aquaculture operations is a temporal scale that will become increasingly important, as exemplified in the Welfaremeter case study presented later in this review.

The interaction of spatial and temporal analyses is also important, an obvious application being land-use changes, and the way these affect aspects such as the environmental drivers for aquaculture of bivalve shellfish and seaweeds, which extract their food resources from the natural environment. Changes in spatial patterns through time are fundamental to aquaculture planning and management, e.g. accurate data on distribution and stocking density of various species, incidence of disease and changes in mortality. From a technical standpoint, they may be limited by the quality of spatial data and the availability of time series at specific locations, but the importance of GIS tools for presentation and understanding of scales and interactions cannot be overemphasized.

Data and information

Data and information types

The data that are needed for management and decision-making are similar across most aquaculture operations (Table 2). However, the space and time resolution of the data sets is dependent on the scale of the aquaculture operation and also on whether it is a single managed entity or an aggregation of independently managed entities. Consequently, the data acquisition approaches and needs expand with the scale of the aquaculture operation and become a system-scale requirement when placed in the context of marine spatial planning, ecosystem-scale carrying capacity assessment, ICZM and responsible management of inland capture fisheries resources.

TABLE 2

Thematic data collection for use of virtual tools, applied on scales ranging from individual farm to watershed

Issue	Key variables *
Morphology & climate	Topography, bathymetry, rainfall distribution, air temperature, wind speed, relative humidity
Water availability, inputs & exchange	Volume, seasonal & annual hydrographs, tidal range & prism, current velocities, residence time
Water quality	Temperature, alkalinity/salinity, suspended matter, nutrients, organic detritus (POC or POM), dissolved oxygen, chlorophyll, extent of submerged aquatic vegetation, xenobiotics, microbiology
Environmental interactions	Fouling, pathogens, extent of submerged aquatic vegetation, benthos
Culture practice	Timing of seeding & harvesting, mortality, cultivation density, size range, feeding (in the case of finfish & shrimp)
Socio-economics	Business fundamentals, infrastructure, direct employment, economic multipliers, use of vessels, etc

Terminology: particulate organic carbon (POC); particulate organic matter (POM).

* The most relevant variables are indicated, but as this is a non-exhaustive list it could also include soil type, roads, cities, locations to markets, plant cover, demography, land use patterns, etc.

Acquisition

Water quality data sets are acquired via discrete water samples and automated sampling systems. Automated water quality sampling systems for small and large-scale aquaculture systems have been available for many years (see review in Lee, 1995) and are considered routine measurements. Similarly, freshwater availability and input can be obtained through gauging of rivers and tributaries, and these measurements are routine in many countries. *In situ* data can be readily acquired at the farm scale (whether in a pond, estuary or coastal area of an ocean) by informed placement of sensor and/or mooring arrays which return information on local environmental conditions.

The spatial scale of *in situ* measurements can be expanded to the system scale by use of satellite-derived remotely sensed data (Table 3). Chen, Zhang and Hallikainen (2007) provide an example of combining satellite-derived and *in situ* data sets for water quality monitoring at a scale of a system of river basins. The algorithms used to obtain derived products from satellite observations (Table 3) were developed for open-ocean temperate waters (see Hooker and McClain, 2000), but there are specific algorithms for coastal waters. Images from near the coast may be data-poor, since there are data flags and aspects of atmospheric correction meant to improve data quality for open ocean. However, awareness of these restrictions and careful removal of data flags can lead to greater recovery of ocean colour information close to the coastline (e.g. Hu *et al.*, 2004).

To maximize the utility of remote sensing data, which is often a cost-effective approach in information-poor regions, *in situ* data sets should be used to establish and calibrate algorithms for applications to estuarine and nearshore coastal waters where aquaculture systems are likely to be established. In particular, algorithms that allow detection of harmful algal blooms (HABs) are critical to maximizing the production of farm-scale operations because satellite remote sensing is a tool that can potentially provide early detection (and warning) of HAB events. Further, characterization of vegetation and land cover changes in watersheds and coastal environments which affect runoff and discharge to coastal bays and estuaries is possible with satellite-based observations (Table 3) and provides a means for monitoring the effects of aquaculture operations at watershed scales.

Techniques that allow integration and synthesis of satellite and *in situ* data are required for these data to be fully utilized to provide estimates of system-scale carrying capacity. Significant efforts have been made using GIS technology to combine disparate data sets (Nath *et al.*, 2000) for natural resource management. These approaches will become more important as the volume and types of data increase and as aquaculture facilities expand.

Frameworks that couple circulation, lower trophic level, shellfish/finfish growth, population and financial and profit models provide another important

TABLE 3
Remote sensing data

Sensor	Data	Example derived data products	Data availability
Very High Resolution Radiometry (AVHRR)	Sea surface temperature	Surface heat flux	http://nsidc.org/data/avhrr
Sea Wide-Field-of-Viewing (SeaWiFS)	Ocean colour, water column light	Turbidity, chlorophyll, primary production, POC, CDOM	http://oceancolor.gsfc.nasa.gov
Moderate Resolution Imaging Spectroradiometer (MODIS)	Ocean colour (chlorophyll), water column light	Turbidity, chlorophyll, primary production, POC, CDOM	http://oceancolor.gsfc.nasa.gov
LandSat Thematic Mapper (TM)	Vegetation & land cover type	Land cover, land use change	http://landsat.gsfc.nasa.gov
Enhanced Thematic Mapper (ETM)	Vegetation & land cover type	Land cover, land use change	http://landsat.gsfc.nasa.gov
Light Detection And Ranging (LIDAR) systems	Elevation	Biomass measurements, land cover	Various
Compact Airborne Spectrographic Imager (CASI)	Optical properties	Biomass measurements, land cover	Various

Terminology: particulate organic carbon (POC); particulate organic matter (POM); coloured dissolved organic matter (CDOM)

data synthesis and integration tool (e.g. Ferreira *et al.*, 2008a,b, 2009). The case studies described later variously use combinations of GIS and coupled modelling frameworks for synthesis and integration of data sets, and the output from this for decision support and management of aquaculture operations. These modelling systems require extensive *in situ* and remotely sensed (e.g. Table 3) data sets for model development and evaluation.

Accurate representation of water circulation is central to estimating production and carrying capacity of aquaculture systems (e.g. Guyondet, Koutitonsky and Roy, 2005). The residence time and exchange of water, variables that are important for aquaculture farm systems, can be estimated from current meter, tidal gauge and drifter measurements. These data can be combined with a three-dimensional hydrodynamic model to estimate flow, exchange and residence time over multiple space and time scales and to undertake scenario testing. The community expertise and knowledge of circulation models is greatly improved and community-based models now exist (e.g. the Regional Ocean Modeling System (ROMS, <http://myroms.org>); Princeton Ocean Model (POM); the Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM); and the Generalized Environmental Modeling System for Surfacewaters (GEMSS)) that have been applied to a range of environments and have large user communities. Implementation of regional circulation models requires local understanding for model development and environmental data for evaluation of simulations.

Climate simulations provide a valuable data resource for site selection for new aquaculture facilities or for projecting system carrying capacity or long-term production from existing facilities under various climate scenarios. The development of approaches to downscale the output from climate models to regional scales (e.g. Wilby *et al.*, 1998; Wood *et al.*, 2004; Salon *et al.*, 2008; Melaku Canu *et al.*, 2010) will allow assessment of potential effects of climate warming on rainfall patterns, precipitation and freshwater fluxes.

Other techniques such as life-cycle analysis, human appropriation of primary productivity and ecological footprint are described in a review on environmental impact assessment (EIA) and monitoring in aquaculture by FAO (2009).

Availability and data sharing

In order to gauge development and management prospects for aquaculture, there is a need to measure impacts imposed on aquaculture from anthropogenic sources and through natural variation in the environment. In turn, it is essential to have an appreciation of the status of ecosystems in which aquaculture resides because aquaculture issues (generally related to environmental, social and economic changes in the context of the EAA) have to be resolved within broader competing, conflicting and complementary uses of land and water. The same is true when evaluating aquaculture's potential impacts on the environment as well as on social and economic systems. For these tasks, spatial data relating to ecosystems and social, economic and administrative realms are required.

As part of a review aimed at evaluating the status of spatial tools, decision-making and modelling to support the implementation of EAA (Kapestsky, Aguilar-Manjarrez and Soto, 2010), an assessment of two broad kinds of spatial data was made: (i) data on large ecosystems already spatially defined; and (ii) spatial data that could be used to define ecosystem boundaries as well as for other uses in aquaculture development and management, both generic (e.g. administrative boundaries) and local (e.g. environmental hotspots). The following conclusions were reached on the availability and gaps in spatial data:

- Examples in aquaculture of the use of environmental data (relating to EAA Principle 1, ecosystem functions) are common. In contrast, examples of the use of social and economic spatial data (relating to EAA Principle 2 on human well-being and equity), and spatial data used to assess other sectors, policies and goals (EAA Principle 3) are much less common. However, this is not necessarily due to lack of data. Rather it could be because of a lack of impetus to use it and perhaps a more generic failure to employ the multidisciplinary approach (natural/social/economic) required by the EAA.
- Relatively high-resolution data, such as would be used at the EAA farm and waterbody/aquaculture zone scales, are needed to spatially resolve environmental, social, economic and administrative issues in aquaculture.

- There is a vast amount of mainly low-resolution/large-scale spatial data freely available on the Internet that could be potentially important for aquaculture at the global and regional scales.
- Many of these datasets could also be useful at the national and subnational levels, but considerable effort will be required: (i) to find the data and then; (ii) to determine the quality and applicability of the spatial data relative to the appropriate resolution, spatial and temporal coverage.
- The demand for spatial data is already greatest where most of aquaculture's social, economic and environmental issues are focused, namely at the farm, watershed/waterbody and aquaculture zone scales of the EAA, but such data are likely to be less readily available in developing countries; this may be compounded by a lower regulatory capacity.

Bundy *et al.* (2009) recently reviewed the issue of data sharing with respect to remote sensing products and identified a number of promising avenues for this purpose, including interdisciplinary working groups, Web-based portals which simplify product access (e.g. www.borstad.com/grip.html), and capacity-building networks such as ChloroGIN (<http://chlorogin.org>) and MyOcean (<http://myocean.eu>).

Available tools

Role of tools

Virtual technology includes a number of techniques that have emerged over the past decades, such as data objects for storage, processing and representation; GIS; and simulation models of various types (Table 4). The common link among these is their abstraction of physical (real) systems, either because they provide an image of that reality, which can be layered and manipulated, and/or because they can be used to predict a state change on the basis of real or scenario-based forcing. In combination, these technologies constitute a powerful arsenal that can be molded into instruments appropriate for decision-makers.

TABLE 4
Virtual technology: objectives, scales, and example applications and tools

Objective and issues	Technology	Scale	Applications
<i>Control production</i>			
Control the production process	Information technology, automatic sensors, etc.	Microscale (farm)	Use of information technology in aquaculture (Bostock, 2009)
<i>Optimize production</i>			
Define the best set of production parameters with respect to environmental, economic & social benefits	Mathematical models	From microscale (farm) to mesoscale (ecosystem/ social/ economic)	The FARM Aquaculture Resource model (FARM) (Ferreira, Hawkins and Bricker, 2007)
<i>Map resources & environment, spatial & temporal indicators</i>			
Evaluate the potential for exploitation of living resources, taking into account ecological services & human activities, as well as environmental changes & risks for aquaculture	GIS, remote sensing	From mesoscale (ecosystem) to micro-scale (farm)	Remote sensing in fisheries & aquaculture (IOCCG, 2009)

TABLE 4 (Continued)

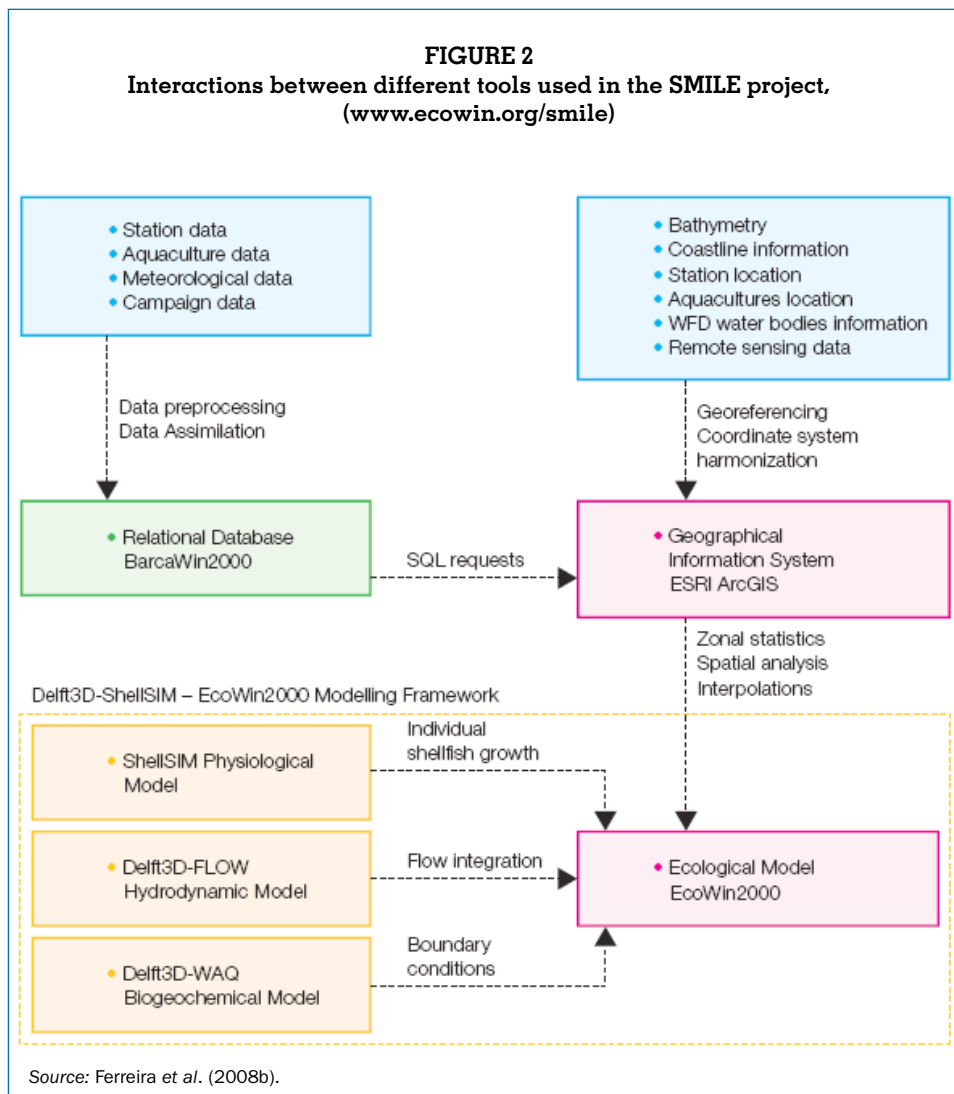
Objective and issues	Technology	Scale	Applications
<i>Risk assessment</i>			
Evaluate the environmental risk posed by aquaculture activity, in order to improve management, define best practices & define monitoring plans	Risk assessment handbook, mathematical models, expert knowledge, literature review, monitoring	From micro (local) to macroscale (transboundary)	Understanding & applying risk analysis in aquaculture (Bondad-Reantaso, Arthur and Subasinghe, 2008)
<i>Build indicators of sustainability</i>			
Evaluate the sustainability of resource management by taking into account the social, economic & ecosystem concerns	Stakeholder fora; enquiries; database regarding economic, social & environmental indicators; life cycle assessment (LCA)	Mesoscale (economic sector)	<ul style="list-style-type: none"> - Environmental analysis of the Norwegian fishery & aquaculture industry (Ellingsen, Olaussen and Utne, 2009) - Assessment of sustainable development of aquaculture (Aubin, 2008) - Consensus project to bring together stakeholders to measure the path towards sustainable aquaculture in Europe (http://euraquaculture.info)
<i>Assess system changes</i>			
Allow adaptation to changes due to other human activities or environment	System approach, mathematical models	From meso-(regional) to macroscale (national, transboundary), social/economic/ecosystem integration	An integrated modelling approach for the management of clam farming in coastal lagoons (Marinov <i>et al.</i> , 2007)
<i>Communication and learning</i>			
Improve/increase social acceptance of aquaculture, scientific & technical knowledge, political awareness, stimulate innovation, etc.	Web-based technologies, e-learning, social fora, technical networks, demonstration tools	From meso-(regional) to macroscale (national, transboundary)	Use of information technology in aquaculture (Bostock, 2009) European Thematic Network in aquaculture, fisheries and aquatic resources management (AQUA-TNET) (www.aquatnet.com/index.php/26/about-aqua-tnet)

Types of tools

Figure 2 provides an example of how a range of tools can be combined for system-scale aquaculture management. The upper part of the figure deals with the requirements for data and the tools used to process discrete water samples, spatial (e.g. bathymetry) and socio-economic (e.g. aquaculture, legislation) data into information that can be used in models, for input, validation, constraint management and scenario development.

The lower part of Figure 2 shows how modelling tools working at different time, space and functional scales (individual shellfish growth models, system-scale detailed circulation models, coarser grid ecological models for decadal simulations) can be combined into a decision support system. In this case, the system is distributed, allowing stand-alone use of the various tools.

In the Sustainable Options for People, Catchment and Aquatic Resources (SPEAR) project (Ferreira *et al.*, 2008a; <http://biaoqi.org>), this approach has been further extended with the incorporation of catchment modelling by means of the Soil and Water Assessment Tool (SWAT, Nobre *et al.*, 2010). This addition allows managers to explicitly couple watershed uses and their influence on coastal discharges with aquaculture yields and ecosystem impacts.



Tools can be developed for mandatory regulation purposes, and integrated for decision support in management systems. The MOM (Modelling-On growing-Monitoring) system (Ervik *et al.*, 1997) is developed and mandatory by regulation in Norway, for monitoring the effects on the bottom and on benthic fauna under and near farming facilities. The methods describe how effects on the seabed are to be monitored, and which limit values (environmental standards) are to be applied to assess whether such effects are acceptable. Based partly on the MOM system, an integrated management system MOLO (environmental monitoring – location) has recently been launched to regulate a broader scale of environmental effects and area adaptation in aquaculture. Localization will be a central feature of the new system for zoning and environmental adaptation. Part of this will involve guidelines for coastal zone management planning for aquaculture areas regulated by the Norwegian Planning and Building Act.

In Scotland, DEPOMOD is used in regulating salmon farm maximum biomass and also for consenting the discharge of infeed sealice medicines. DEPOMOD couples a particle tracking model (of waste feed and faeces) and an empirical benthic response model to yield predictions of benthic impact based on environmental parameters (e.g. bathymetry, depth, currents) and farm management (e.g. cage layout, feed inputs) (Cromey, Nickell, and Black, 2002; Cromey *et al.*, 2002).

Novel management

Overview

A brief overview is provided below of how virtual tools can address the specificities of different types of aquaculture, providing novel approaches to management by means of the application of models of different types. Such models may be used as a stand-alone resource, combined in order to take advantage of complementary strengths, and leveraged by means of remote sensing and other technologies. The issues vary depending on whether the cultivation is intensive or extensive, on the type of food source (i.e. feed, organic extraction, inorganic extraction), and on the combination of species used. The first section focuses on feed-based culture, the second on bivalve shellfish, and the final part on IMTA.

Feed-based (cage aquaculture, pond)

At present, virtual management tools for feed-based culture are focused primarily on site selection and assessment of sustainable production, based on the holding capacity of the environment (cage culture) and on the minimization of waste waters (pond culture). Some studies also present the development of decision support systems (DSS), which could help farmers in selecting sites, species and, to a certain extent, provide guidelines for management practices. The MOLO system in Norway is currently under development, and includes (i) AkvaVis (see Case study 3); (ii) integration of hydrodynamic modelling, welfare and production in salmon pens; (iii) food availability to mussels; (iv) wave exposure;

and (v) risk of disease. This is one example of new integrated/comprehensive management systems, although as yet not implemented in management. Such tools may also include an economic component, thus allowing users to estimate profit (Halide *et al.*, 2009) and in some instances, optimization techniques may also be incorporated (Bolte, Nath and Ernst, 2000).

However, these examples are still relatively rare, and a comprehensive, systemic approach to the optimization of management practices is still lacking, in particular in cage culture. Furthermore, most models and DSS developed in the last decade do not provide quantitative sustainability assessment in the form of holistic indicators, based on matter and energy budgets. Some examples of application of this class of indicators to “mature” aquaculture productions are emerging in the literature: Martinez-Cordero and Leung (2004) proposed environmentally adjusted production indicators for assessing the sustainability of shrimp farming in Mexico; D’Orbcastel, Blancheto and Aubin (2009) compared the sustainability of two trout farming systems by means of life cycle assessment (LCA) analysis. These tools and indicators could be helpful both for identifying inefficiencies and providing the basis for ecolabelling aquaculture products, thus increasing their social acceptability and, potentially, the profit of those farmers who follow more sustainable practices.

Another area of improvement is represented by the development of management tools based on the combination of mechanistic and statistical models, which would help decision-makers to take into account the often large uncertainty in both environmental and economic drivers that cannot be controlled by farmers. In this context, risk analysis may be a viable approach (Soto *et al.*, 2008; GESAMP, 2008), but existing tools could also be improved by adding global sensitivity and uncertainty modules, which could allow uncertainty estimates in the relevant outputs (biomass yield, expected revenues, etc.) with respect to uncertainty in the drivers and model parameters. This change may also lead to the selection of different “optimal” practices, since sometimes “optimal” solutions found by linear programming tools are not robust in respect to fluctuations in the input data.

Lastly, existing tools may not be entirely suitable for the implementation of “adaptive management”, which is regarded as a desirable practice in EBM, since they often rely on “static” data archives. In this context, the World Wide Web should probably be taken into consideration as a potential delivery medium for real-time data concerning non-manageable drivers, such as the occurrence of HABs or acute water pollution events, weather and market prices, on which short-term prediction could be based. Dedicated Web sites can either allow direct access to these data or provide appropriate links. These data could be combined with high-frequency site-specific data concerning the evolution of key water quality variables within ponds/cages and models, as is described in the welfaremeter case study (Case study 6) presented below.

Shellfish farming

Shellfish production relies heavily on the resources provided by the environment (unpolluted waters, adequate trophic resources, in many instances seed) and requires the allocation of rather large areas within coastal waterbodies. Therefore, on the one hand, the set of “control variables” which can actually be managed by a farmer is reduced, in comparison with feed-based aquaculture and, on the other, the separation between the farm scale and the regional scale is less sharp, in particular in semi-enclosed embayments and lagoons. In these environments, the competition for resources among farmers, who may also be part-time fishermen, may be high, and in many cases is mitigated by the formation of cooperatives which collectively manage a certain number of farms.

The estimation of the production and/or environmental carrying capacity at a water basin/regional scale is still the focus of the majority of studies concerning the assessment of the environmental sustainability of shellfish farming. These studies do not in most cases address economic sustainability. Recently, a more comprehensive approach, based on a dynamic ecological-economic model, was proposed (Nobre *et al.*, 2009), taking into consideration to some extent the within-region variability. Another example of ongoing research is the EU Science and Policy Integration for Coastal System Assessment (SPICOSA) project (www.spicosa.eu), where partners are trying to model interlinks among ecology and socio-economics at several study sites.

These types of approach should be further developed and coupled with GIS, which, in general, could provide a suitable platform for including other constraints related to conflicts of use and water quality issues. For example, assessment of the contamination of shellfish by heavy metals and organic toxicants is not usually taken into consideration, but could be taken into account by coupling individual/population dynamics models with simple bioaccumulation models. Such models could also point to critical or subcritical situations, thus setting the scene for cost-effective monitoring. An emphasis on shellfish welfare and food security, which could be achieved through monitoring, proper certification and traceability, would improve consumer acceptance and potentially increase both revenue and profit. Therefore, estimation of the uncertainty in the biomass yield and adaptation of the above strategies in relation to short-term prediction are even more crucial for maximizing profits or minimizing losses due to adverse events. Among those, HABs certainly represent one of the major problems. Early warning and short-term prediction of the dynamics of HABs, based on the integration of real-time monitoring and operational hydrodynamic models, would certainly improve the capability of mitigating the adverse effects of HABs. Shellfish farms are often closed following rains due to land-based pollution (Conte, 2007); monitoring and modelling based on virtual technologies would seem to be an excellent way to address this.

Integrated Multi-Trophic Aquaculture

IMTA is indicated as one of the main paths towards sustainable aquaculture (Soto, 2009). However, farm-scale applications are still limited, in particular in Europe, perhaps due to the higher costs associated with IMTA and the higher complexity of IMTA farms. Another important element is the identification of markets for successful placement of the full range of IMTA products, which relates both to cultural aspects and to producer awareness (for instance, a finfish farmer may not be aware of commercial opportunities for agar manufacture for co-cultivated seaweeds).

Virtual management tools have a great potential for exploring possible alternatives and assessing the potential benefits if ecological and economic models are integrated; the goal is to provide a realistic estimation of the medium to long-term profitability of IMTA. IMTA began thousands of years ago in the People's Republic of China, and was initially developed by farmers because this approach produced much more output than monoculture for an identical input. In other words, IMTA has the potential of being economically more cost effective; it has a higher average physical product (APP). Although papers on this topic first appeared in western journals several decades ago (Tenore, Goldman and Clarner, 1973; Ryther *et al.*, 1975), IMTA is rarely implemented in the west, even though fish farming companies on both coasts of Canada have adopted aspects of IMTA. However, it is widely and extensively used both in China (Li, 2006, collects 17 papers on experimental combinations of cultivated species in IMTA), where it is the traditional form of aquaculture, and in the developing countries of Southeast Asia. The application of IMTA has been mainly driven by economic factors, but more and more interest has been focused in recent years on its significant advantages with respect to environmental sustainability.

Virtual technology such as GIS, remote sensing and modelling has begun to be extensively applied in this traditional industry through international scientific programmes (e.g. the EU SPEAR project: Ferreira *et al.*, 2008a). Virtual management tools, particularly models that integrate ecological and economic components (Whitmarsh, Cook and Black, 2006; Nobre *et al.*, 2009) will play an important part in the future development of IMTA both locally and globally, and in assessing its role in ICZM.

Case studies

Kapetsky and Aguilar-Manjarrez (2007) and Ross, Handisyde and Nimmo (2009) provide an overview of decision support using GIS tools for aquaculture. Several descriptions of tools have been published in the last decade (e.g. Salam, Khatun and Ali, 2005; Ferreira, Hawkins and Bricker, 2007; Hossain *et al.*, 2009; Ferreira *et al.*, 2009; Nobre *et al.*, 2010), while information on other tools such as AkvaVis is available through the Web. A synthesis of the main objectives, technologies and examples of application is presented in Table 4.

Additional descriptions of several types of aquaculture models together with some theoretical background and evaluation of indicators can be found on www.ecasatoolbox.org.uk.

In this section, seven case studies (Table 5) have been selected for a more detailed review to illustrate the potential of different types of software

TABLE 5
Summary of case studies using virtual tools for different objectives, species, and scales

	Case Study N° 1 PEI	Case Study N° 2 SPEAR	Case Study N° 3 AkvaVis	Case Study N° 4 UISCE MarGIS	Case Study N° 5 FARM	Case Study N° 6 WELFAREMETER	Case Study N° 7 POND
Main management issue(s)	Ecological carrying capacity	Carrying capacity for Integrated Multi-Trophic Aquaculture	GIS for site selection, carrying capacity & management monitoring in aquaculture	GIS & dynamic modelling to support aquaculture management	Prediction of production, economic outputs & environmental effects over the culture cycle	Real-time monitoring of welfare for cultured finfish, coupling real-time data & models for day to day farm management	Production of shrimp farms in pond culture
Stakeholders	Water managers, aquaculturists	Water managers	Water managers, aquaculturists	Water managers, aquaculturists	Water managers, aquaculturists	Water managers, aquaculturists	Aquaculturists
Location	Prince Edward Island, Canada	Sanggou Bay, China	Hardangerfjord, Norway	Ireland	Valdivia Estuary, Chile	Norway	Venezuela, China
Scale	Bay	Bay	Bay, local	Bay, local	Local (open water)	Local	Local (pond culture)
Cultured species	Blue mussel	Finfish, shellfish & seaweeds	Finfish & shellfish	Shellfish	Shellfish & finfish	Finfish	Penaeid shrimp
Data & information types	Field, experimental	Field, experimental, GIS, remote sensing	Field, GIS, desk-based	Field, experimental	Field, experimental, economic	Field	Field, experimental
Tools & model types	GIS, dynamic system-scale models	Dynamic system-scale models, catchment models, etc. (multilayered)	GIS, socio-economic instruments, models	Combined GIS & dynamic models	Dynamic models, statistical models	Sensors, risk assessment models	Dynamic models
Platform	Console	console/Web	Web	Console	Web/console	Web	Web/console
Decision-support	Licensing, production & environmental effects	Licensing, species combinations, production & environmental effects	Management monitoring, site selection & licensing	Licensing, production & environmental effects	Production, economic optimization, environmental effects	Production, disease & animal welfare	Production, economic analysis & environmental effects
Costs (medium: USD104–105; high: USD 105–106)	Medium	High	Medium	Medium	Medium	Medium	Medium
Time (estimated for a 5–10 person team)	Months–years	Years	Months–years	Months–years	Months	Months	Months
Technical skills (high: develop & apply models, medium: apply existing models)	High	High	High	High	Medium	Medium	Medium

products in supporting ICZM, assisting water managers in the licensing process (system scale), and helping aquaculture farmers in selecting sites and optimizing production. The case studies shown focus also on various aspects of environmental sustainability.

The selected case studies represent a broad sampling across geographic regions. They vary with regard to the degree to which outcomes have been used for practical decision-making and to the complexity of the analytical methods used. Each of the case studies is presented in the following format:

- source of the work;
- objectives;
- target audience;
- geographic area and scale of analysis;
- analytical framework and results; and
- relevance of virtual technology and decision support for management.

Case study 1: Prince Edward Island: system-scale carrying capacity (source: Filgueira and Grant, 2009)

Objectives

Canada's smallest province, Prince Edward Island (PEI), is home to the nation's largest blue mussel (*Mytilus edulis*) culture industry (80 percent of production), with an annual yield of 17 000 tonnes. Typical problems of extensive shellfish culture have been encountered, including overstocking and reduced growth, fouling by tunicates and eutrophication impacts. Although there are studies of mussel culture in various bays of PEI (e.g. Cranford, Hargrave and Doucette, 2009), the location with most research focus has been Tracadie Bay, on the north shore, which includes 20 percent of PEI's production. In terms of research, simulation models of circulation, biodeposition, seston depletion and mussel growth have been developed, coupled to comprehensive field programmes (e.g. Grant *et al.*, 2008).

Ecosystem modelling provides a method of managing entire culture ecosystems, with the goal of developing sustainable levels of aquaculture through marine spatial planning. In this example from eastern Canada, the modelling approach is presented, as well as criteria for sustainability within the model context. Despite this capability, only some of the research has been closely matched to management schemes.

Target audience

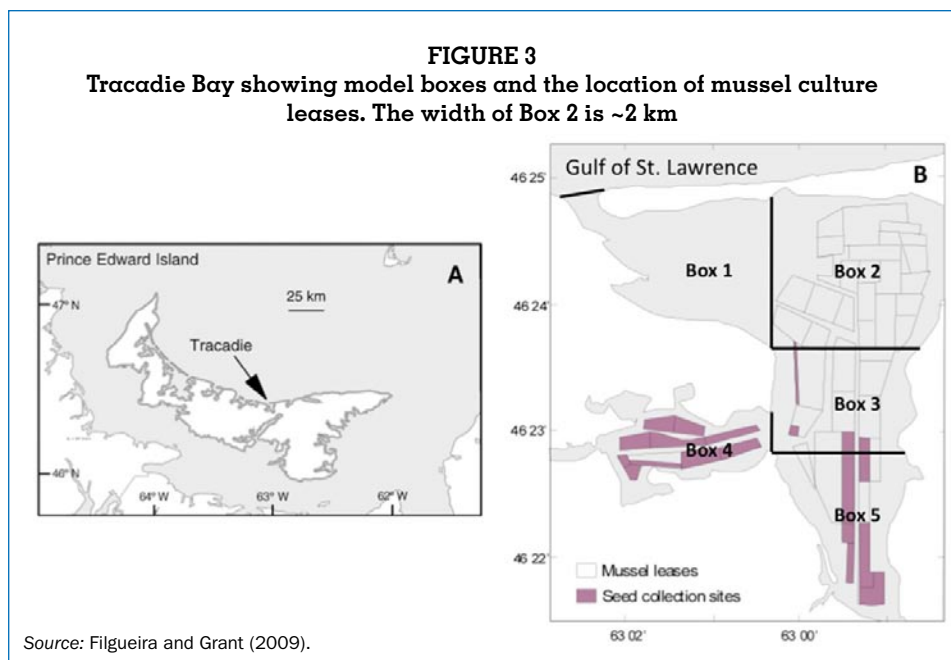
The regulatory authority, the Department of Fisheries and Oceans Canada (DFO), has an advisory capacity established with the mussel industry. The industry is integrated within the PEI Aquaculture Alliance. Naturally, mussel growers seek to maximize production in the bay, and form management committees with DFO. Strategies such as reduction in longline spacing (Comeau *et al.*, 2008) have been utilized, but trial and error adjustments are risky to implement and do not

integrate the interaction between culture in different parts of the bay. The virtual tool most targeted toward culture advice is that of Filgueira and Grant (2009), where a box model of seston depletion was constructed for Tracadie Bay. Under different stocking densities, resulting seston depletion was observed and compared to a quantitative sustainability criterion as detailed below.

Geographic area and scale of analysis

The 130 growers of PEI use the many shallow barrier island estuaries typical of the island's sedimentary coastline. Longline culture is practiced exclusively. American cupped oysters (*Crassostrea virginica*) are also grown, but there is primarily a bottom fishery for oysters. Due to the accessibility of culture areas, protected waters and a productive environment, mussel culture occupies significant portions of many bays. Tracadie Bay is among the most intensively studied coastal areas of eastern Canada. Culture maps demonstrate the extent to which mussel farms dominate the surface area of the bay (Figure 3).

Depths range to only 6 m and much of the bay is 3 m deep. Discrete bays with narrow inlets arguably constitute distinct ecosystems, separated from adjacent systems by open ocean. Research and management at this level may therefore be considered ecosystem scale.

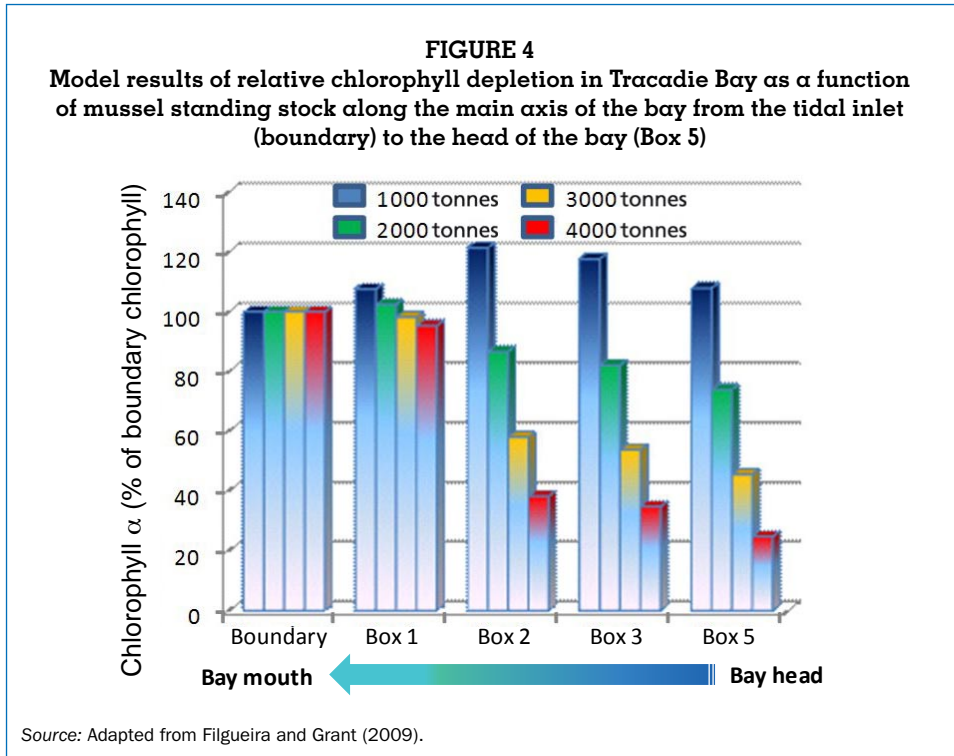


Analytical framework and results

Although carrying capacity may have a variety of contexts and definitions, Filgueira and Grant (2009) worked with ecological carrying capacity, meaning that the trophic functioning of the system would not be degraded by the level of culture deployed in the bay.

In practical terms, there was a focus on the limiting resource for bivalves, phytoplankton measured as chlorophyll. If bivalves deplete this resource far below natural levels, food for plankton, including larval fishes, as well as benthic organisms, would be reduced. These dynamics were simulated using a box model (Figure 3), and the output from a 2D circulation model of the bay.

Chlorophyll at the tidal inlet is a measure of primary production entering the system through boundary conditions; the ratio of internal chlorophyll to boundary chlorophyll is a measure of how mussel grazing (among other internal sinks) reduces this supply. The annual variation in this ratio is an indication of noise in the system, determined to be Coefficient of Variation = 27 percent in this study. These values are plotted for each box as a function of mussel stocking biomass (Figure 4). It is important to recognize that there is generally exchange limitation within the bay from outer (Box 1) to interior boxes (Box 5), including reduced mussel growth (Waite, Grant and Davidson, 2005). It can be seen that for a standing stock of 1 000 tonnes total fresh weight (TFW), there is no depletion, and even positive effects as primary production increases chlorophyll within the bay. For a doubling of this standing stock, there is some decline in relative chlorophyll toward the upper bay, but within the expected variation of changes in phytoplankton biomass compared to boundary values. The latter standing stock is thus sustainable according to a functional criterion.



For even higher standing stock, chlorophyll is severely reduced compared to its natural range of variation, and the ecosystem is presumably compromised. Adjusting the standing stock in the various boxes is one solution to these limitations, but becomes an optimization problem, requiring a further stage in the modelling. Therefore, using a spatially coarse box model with objective standards for carrying capacity defined by the seston dynamics, aquaculture can be managed on the basis of ecosystem-level considerations.

Relevance of virtual technology and decision support for management

Mathematical models comprise one of the most powerful virtual tools due to their predictive capability arising from retrospective analysis – the ability to run “what-if” scenarios. Box models are obviously less spatially resolved than fully spatial models, and as a result less inclined toward mapped results. However, the transects of seston depletion we have shown, including a limit for acceptable change, allow a visual view of seston levels under various stocking scenarios.

Optimization routines can be used to select biomass levels that do not steepen the depletion gradient excessively. There are shellfish growth rates associated with these farming densities, which can also be used in predicting the consequences of food density for bay yield. Decision support is most likely undertaken with researchers, but the objectives of either managers or shellfish farmers are the prime consideration in applying the model. Careful consultations with these stakeholders is required, as well as the ability to validate the model with field measurements, such as bivalve growth.

Case study 2: SPEAR – Sustainable Options for People, Catchment and Aquatic Resources

(source: Ferreira *et al.*, 2008a)

Objectives

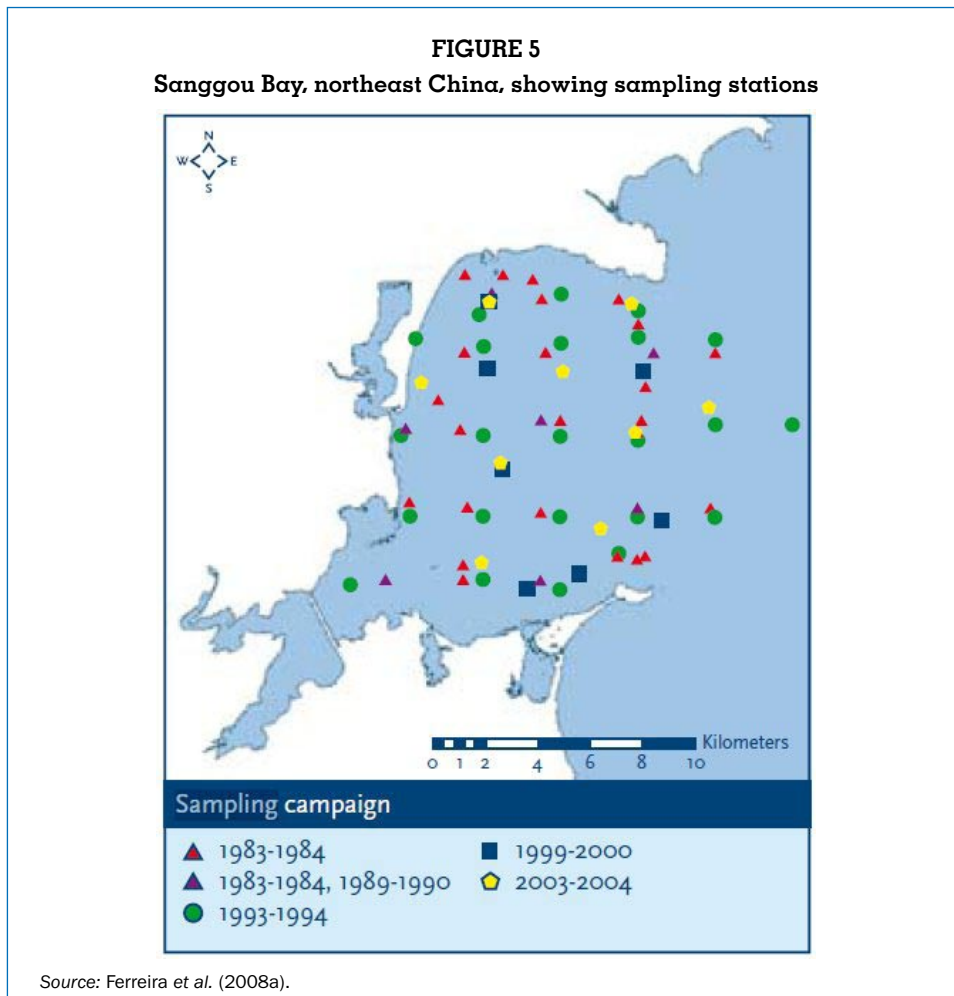
The general objective of SPEAR (Ferreira *et al.*, 2008a; <http://biaoqiang.org>) was to develop and test an integrated framework for management of the coastal zone, using two test cases where communities depend primarily upon marine resources, of which a large component is aquaculture of finfish, shellfish and seaweeds, often in IMTA.

Target audience

This type of system-scale model of carrying capacity is aimed specifically at water managers, planners and licensing authorities. It provides information on the system as a whole, with an appropriate degree of spatial discrimination, in order to set overall limits for sustainable aquaculture, which may then be used to inform more detailed (local-scale) siting and licensing.

Geographic area and scale of analysis

Two contrasting coastal systems in China were used as study areas. Sanggou Bay (Shandong Province) is in a northern rural area and Huangdun Bay (Zhejiang Province) in a heavily industrialized area with substantial human pressure on both local and regional levels. The case study reported herein refers specifically to Sanggou Bay (37°N, 122°E), located within the jurisdiction of the small (population 150 000) city of Rongcheng. Weihai is the closest larger city, with a population of 2.5 million. Sanggou Bay (Figure 5) is a semicircular embayment with an open boundary to the sea. The water exchange is chiefly forced by the tides, and the bay is well mixed, both horizontally and vertically, with a residence time of 5–20 days.



The aquaculture production in Sanggou Bay is 263 500 tonnes/year and consists of cultivated species of seaweeds, shellfish and finfish, of paramount importance for community income and livelihood, both locally and regionally.

Analytical framework and results

The well-tested EcoWin2000 (E2K) ecological model (Ferreira, 1995; Nunes *et al.*, 2003; Nobre *et al.*, 2010) was used to simulate aquaculture production of multiple shellfish species simultaneously. Organic inputs from finfish aquaculture and seaweed production were also modelled. Circulation was modelled by coupling outputs of the detailed hydrodynamic simulations offline (using the Delft3D model), upscaled to a 3D ecological model with two vertical layers (16 boxes). The water flows derived for a grid with 60 000 cells and with a timestep of three minutes were upscaled to larger boxes and a timestep of one hour, and used to force the transport of substances in the larger box model.

The biogeochemical state variables are simulated for each box using as forcing functions (i) boundary loads: catchment (simulated using the SWAT model), ocean boundary, using measured data, and aquaculture emissions; and (ii) light climate and water temperature. The approach thus brings together a set of models that run at different time and spatial scales, and for different ecosystem components. A key feature of the general modelling approach is to integrate the several models in order to develop a robust ecosystem modelling framework; this requires the assembly of a wide range of data. The general framework for application is described in Ferreira *et al.* (2008a) and Nobre *et al.* (2010).

The E2K outputs for harvested shellfish and macroalgae are shown in Table 6. It should be noted that the only validation possible for these results is by comparison to landings data, which are somewhat unreliable. For that reason we discourage a modelling approach where models are calibrated to match reported harvests, and in this application of E2K, the calibration and validation were performed for several water quality variables, including drivers of shellfish growth, and for the underlying models for catchment loading, water circulation and individual growth.

Despite this caveat, for Sanggou Bay the modelling system led to the harvest results shown, which compare well with the survey data.

TABLE 6
Landings data and modelled harvests for Sanggou Bay (tonnes/year)

Pacific cupped oyster (<i>Crassostrea gigas</i>)		Farrer's scallop (<i>Chlamys farreri</i>)		Kelp (<i>Laminaria japonica</i>)		Total	
Landings	Model	Landings	Model	Landings	Model	Landings	Model
178 872	175 382	5 000	5 148	84 500	83 754	268 372	264 284
	(-2%)		(+3%)		(-1%)		(-1.5%)

Source: Ferreira *et al.* (2008a).

Relevance of virtual technology and decision support for management

The full ecological model for Sanggou Bay has over 100 state variables, and is able to simulate a period of three years in under five minutes. This makes it possible for decision-makers to quickly examine development scenarios. An example of the use of the model for decision support is summarized below.

Reduction of shellfish culture densities

Shellfish aquaculture is the largest industry in Sanggou Bay, and the major source of revenue to Rongcheng City. Due to the strong desire for increased economic benefit, farmers have substantially increased shellfish seeding density since the late 1990s. However, yields have been limited by a combination of reduced growth (potentially due to overstocking) and infectious diseases, particularly in the Farrer's scallop.

This scenario considers a reduction of 50 percent in seeding density, in order to analyze changes in both harvest tonnage and revenue. Table 7 shows the results of the application of E2K to Sanggou Bay for both the standard and scenario simulations. The results suggest that a 50 percent reduction in stocking density would lead to a 31 percent decrease of Pacific cupped oyster harvest and a 220 percent increase in Farrer's scallop harvest. The simulation results indicate an overall decrease in harvest of 24 percent for a 50 percent reduction in density, suggesting that the carrying capacity of Sanggou Bay is largely exceeded. Additionally, because of the price differential between Farrer's scallop (a high value crop) and Pacific cupped oyster, the total income from shellfish aquaculture is identical.

TABLE 7
Application of E2K to Sanggou Bay, to analyze changes in yield and profitability associated to a 50 percent reduction in shellfish culture

Shellfish species	Pacific cupped oyster		Farrer's scallop	
	Standard model	Reduction scenario	Standard model	Reduction scenario
Seeding density (ind/m ²)	70	35	60	30
Percentage change	–	-50%	–	-50%
Harvest (tonnes)	175 382	121 413	5 148	16 472
Percentage change	–	-31%	–	+220%
Revenue (CYN10 ⁶)	102	72	15	46
Percentage change	–	-29%	–	+207%

Source: Ferreira et al. (2008a).

There is a significant growth depression in Farrer's scallop in the standard simulation, when compared with the scenario, which suggests that (i) the seeding density is too high; and (ii) the food depletion caused by the surrounding large-scale Pacific cupped oyster culture significantly limited the growth of Farrer's

scallop, while their cultivation area ratio is 2.6:1. There is a remarkable growth increase in both species when the seeding density is halved.

Case study 3: AkvaVis decision support system

(Source: Ervik *et al.*, 2008)

Objective

The decision support system AkvaVis (Figure 6) for site selection, carrying capacity and management monitoring is presently under development (Ervik *et al.*, 2008). AkvaVis aims to develop a Web-based interface that will be transparent to public insight and dynamic in the sense that it is adaptable to new knowledge, new regulatory frameworks, and demands from industry and public and private stakeholders.

The challenges of integrated planning and management for aquaculture in the Norwegian coastal zone have prompted the launching of a new cohesive management system MOLO (environmental monitoring – location), under which AkvaVis is intended to be developed as the virtual decision-support tool.

Target audience

The target audience includes all stakeholders in the fields of aquaculture production, management and policy implementation. A user survey (Hageberg, 2008) is part of the current development of the system.

Geographic area and scale of analysis

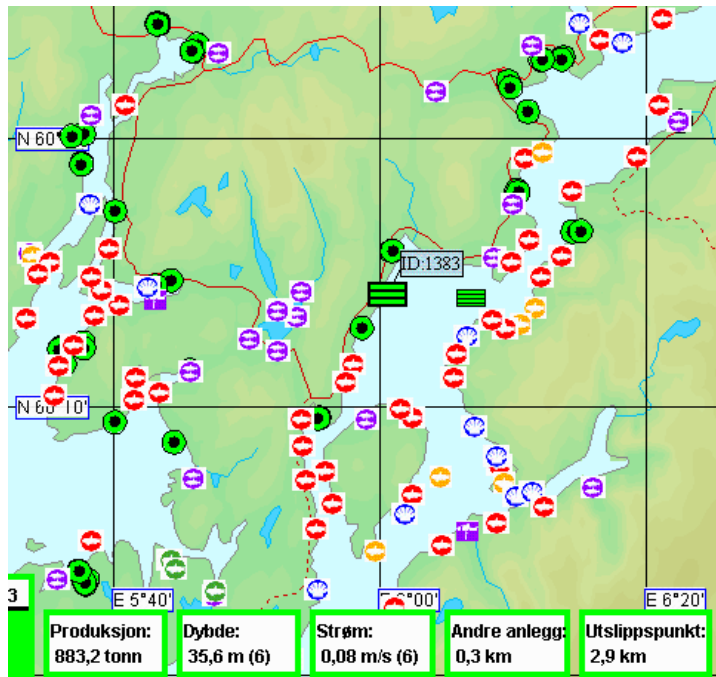
AkvaVis aims at covering the main aquaculture species in Norway, and demonstrations for the blue mussel and Atlantic salmon (*Salmo salar*) in the Hardangerfjord are available at www.akvavis.no.

Analytical framework and results

AkvaVis is built up of three modules that share the same databases and information but apply it for different purposes. The siting module can identify potential farm sites and simulate their carrying capacity, the management module will compile all available information needed by the authorities for aquaculture management, and the application module will aid in an efficient application procedure and ensure that all relevant information is provided. AkvaVis divides the relevant area into grid cells and objects containing quantitative information on localization parameters. The user can insert into the map an “intelligent farm object” that communicates dynamically with a mathematical model using the information in the grid as input for simulating aspects of production and ecological carrying capacity as well as with information on other objects.

Once inserted, the “intelligent object” will thus immediately report back how suitable a given site would be for mussel or fish farming by giving a score for each parameter and a calculated total score on how the requirements are met.

FIGURE 6
The AkvaVis site selection expert system



Source: Ervik et al. (in press).

Siting of a salmon farm will interact with a conformed version of the MOM model (Ervik et al., 1997), assessing the potential effects on the bottom and on benthic fauna returning suitability according to environmental impact standards. AkvaVis is developed using a map client based on the web map service (WMS) standard. The system integrates: (i) data regarding parameters (e.g. currents, aquaculture sites and waste outlets); (ii) expertise (e.g. growth models, rules for weighting parameters and boundary values); (iii) legislation, regulations and directives (e.g. distance to other aquaculture sites); (iv) calculations, visualizations and interactivity with the user; and (v) basic and thematic maps. The interactivity allows the users to immediately see the consequences of their choices.

Relevance of virtual technology and decision support for management

The AkvaVis DSS will provide a hands-on Web-based interface that will give the user immediate response to choices. The siting, management and application modules are purpose-designed to meet some of the prime needs in aquaculture management by authorities and industry.

The transparency to public insight and dynamism to new knowledge, new regulatory frameworks and demands from industry and public and private stakeholders is regarded as important for development of an efficient and trustable tool.

Case study 4: UISCE Project Virtual Aquaculture (GIS modelling application for bay and site-specific aquaculture production scenarios) (Source: Dallaghan, 2009)

Objectives

The objectives of the Understanding Irish Shellfish Culture Environments (UISCE) project were to: (i) develop a suite of computer models to facilitate the prediction of different aquaculture and water quality scenarios which could influence the nature and/or scale of shellfish aquaculture activity in a bay area; (ii) provide a decision support system, based on the suite of computer models, to the aquaculture industry with respect to the best locations and optimal size of shellfish aquaculture sites; and (iii) to provide an information base and liaison facility for industry.

Target audience

The target audience includes all stakeholders in the fields of aquaculture production, management and policy implementation.

Geographic area and scale of analysis

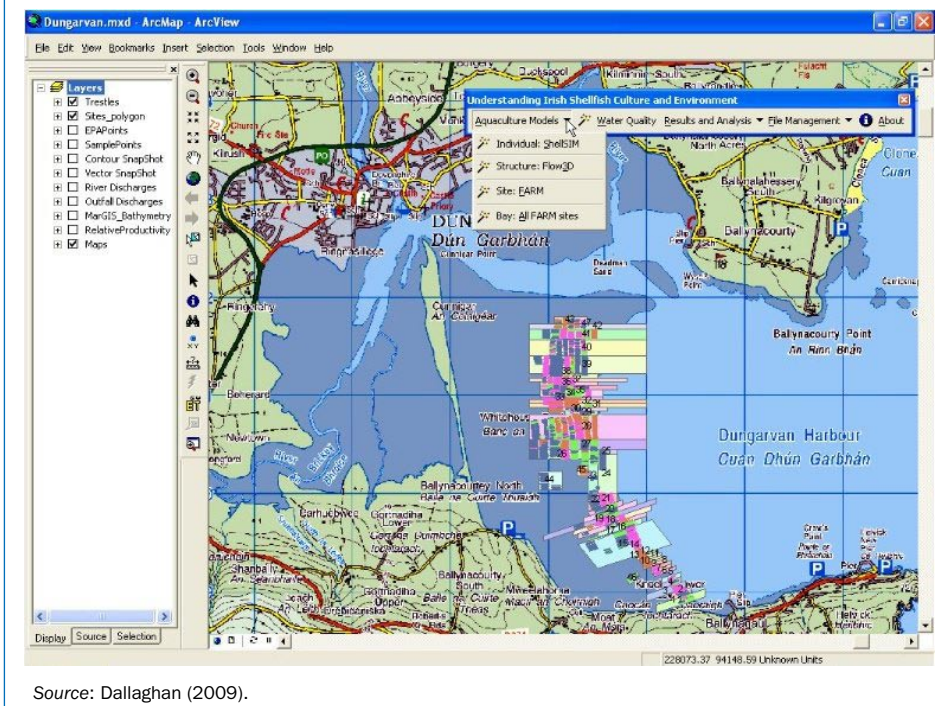
MarGIS™ has been adopted by the Northwest Region of the United Kingdom Environment Agency, and is currently used on the Mersey, Ribble and Severn estuaries and in Morecambe Bay in the United Kingdom.

Analytical framework and results

The MarGIS™ DSS, constructed as part of the UISCE project, is a near real-time interactive software application, tailored specifically for shellfish growers around the Irish coast, which will enable them to optimize their operations and production in a sustainable and environmentally sensitive manner. By using near real-time current conditions, MarGIS™ will allow a farmer to quickly see what effect on his productivity would be expected if he were to make stocking density changes, for example, or to reposition one or all of his mussel lines, or introduce more mussel lines in the vicinity of the existing farm. By allowing the optimization of husbandry techniques such as this, the software encourages farmers and communities to work together.

MarGIS™ has been developed within the ESRI ArcView environment to facilitate location-specific predictions from the suite of computer models and allows for the modelling and reporting on issues surrounding the shellfish aquaculture industry from a “macro” or bay-scale level through to a “micro” or individual animal level (Figure 7).

FIGURE 7
Menu options of the MarGIS™ UISCE application



Source: Dallaghan (2009).

The primary deliverable from the UISCE project is a desktop application that can be used repeatedly by growers with functionality added and refined as required. This system gives growers access to the best science available and the knowledge, in software form, of international experts. The system makes it easier to understand embayment from a food and flow perspective, thus allowing growers to move away from “trial and error” aquaculture. The data generated by this project form an information base for industry and other state agencies. This data can be built upon and put to a variety of uses. An online demonstration of MarGIS™ is available at www.marcon.ie/website/html/margisdemo.htm.

Relevance of virtual technology and decision support for management

MarGIS™ is especially relevant for novel management of aquaculture for a number of reasons: it can be used to infer near real-time scenarios of environmental impacts of aquaculture at both farm and bay scales; the application encourages farmers and communities to work together, thus ensuring stakeholder inputs and participation; it centralizes the best science available in the fields of shellfish growth, aquaculture, water quality and ecological models and it places all this expertise under one roof. The integration of models with the GIS framework and the construction of a mechanism whereby models could communicate to each other was one of the project cornerstones.

MarGIS™ will allow farmers to quickly and accurately identify the carrying capacity of their bay and what impact changes to the density of their farming stock would have on production levels. This was one of the main drivers of the project, with anecdotal evidence of suboptimal growth for mussels in Killary Harbour suggesting that possible over-stocking of some sites in the bay may have been leading to poor growth rates.

Case study 5: Farm Aquaculture Resource Management (FARM) (Source: Silva, 2009)

Objectives and target audience

FARM (Ferreira, Hawkins and Bricker, 2007) was initially developed to provide a simple tool for application by shellfish farmers and a means for rapid screening of cultivation potential in data-poor environments, which typically occur in developing nations. Complementary approaches may be used for carrying capacity analysis, such as remote sensing techniques for chlorophyll, turbidity and other variables (Grant *et al.*, 2009). However, these may be hampered (i) for smaller systems by the available spatial resolution of images; and (ii) for Case II (inshore, brackish) waters, by algorithm accuracy, although this is improving rapidly (e.g. Moses *et al.*, 2009).

More recently, the approach has been extended to finfish cage culture, and as such can also address IMTA. Whether FARM is applied in systems where lots of data are available or in those where better data are needed, the model is a decision-support tool for (i) site selection; and (ii) expansion/optimization of existing farms, and as such of interest to managers, aquaculturists and regulatory agencies.

Geographic area and scale of analysis

The FARM model simulates the individual growth of shellfish and finfish in open water, taking into account food supply and oceanographic conditions, and calculates the distribution of biomass for cultivated species, with an emphasis on the harvestable weight classes. It is designed to be used for local-scale (hundreds to thousands of meters) assessment of carrying capacity.

The FARM model has been tested in the European Union (France, Ireland, Italy, Portugal, Scotland, Slovenia; Ferreira *et al.*, 2009), the United States of America (Puget Sound and Chesapeake Bay), China (Ferreira *et al.*, 2008a) and Chile (Silva, 2009). The Web version has been viewed from 67 countries, from all continents, so it is likely that the model has been applied far more widely.

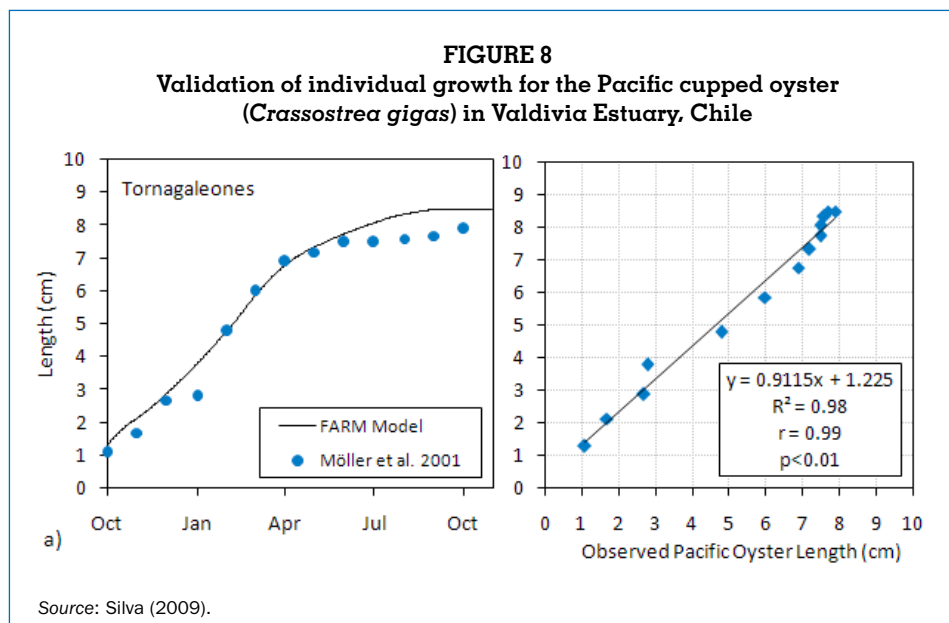
Analytical framework and results

As an example application, FARM was used to test three sites in the small (15 km²) Chilean estuary of Valdivia, to screen for potential oyster farming areas (Silva, 2009).

The individual growth model used for *Crassostrea gigas* (AquaShell™) is based on a net energy balance approach (e.g. Hoffmann *et al.*, 1995; Kobayashi *et al.*, 1997) and draws on functions for feeding, assimilation and metabolism published by various authors (Dame, 1972; Hoffmann *et al.*, 1995; Kobayashi *et al.*, 1997; Ren and Ross, 2001, Brigolin *et al.*, 2009). It simulates: (i) change in individual weight (growth), expressed as tissue dry weight and scaled to total fresh weight (with shell) and to shell length; and (ii) functional dependency on relevant physical and biogeochemical components (i.e. allometry, total particulate matter, temperature and salinity) and partitions the phytoplankton and detrital food resources; and (iii) provides environmental feedbacks for production of particulate organic waste (faeces and pseudofaeces), excretion of dissolved nitrogen and oxygen consumption.

The individual model was validated using experimental growth curves determined by Möller *et al.* (2001) for the Valdivia Estuary and showed a significant relationship ($p < 0.01$) to measured growth (Figure 8).

Data were available at the site area for a one year period for the environmental drivers used in FARM, and the model was used to screen potential growth as shown in Table 8. The model outputs for a standard simulation of *C. gigas* in suspended culture (Table 8, column 2) suggest this is a promising area for oyster cultivation, with fast growth and a good return on investment, as shown by the average physical product (APP = output : input) ratio of 11.6, and by the predicted income. The sediment accretion rate and organic enrichment due to shellfish biodeposits (41 percent increase in POC/year over background sedimentation of organic carbon) are both low.



Two sites at other locations in the estuary were screened, and on the basis of APP found to be borderline suitable (APP = 1.57), and unsuitable (APP = 0.22), even at low cultivation densities, and thus rejected.

A marginal analysis (Ferreira, Hawkins and Bricker, 2007) was performed for profit optimization of the Tornagaleones site by plotting the marginal physical product (MPP, the first derivative of TPP) at increased seeding densities and graphically determining the optimum based on financial data (Table 8, column 3).

TABLE 8
Inputs and outputs of FARM for initial screening, optimization analysis and IMTA at a potential *Crassostrea gigas* farm in the south Chilean estuary of Valdivia

Variable	Tornagaleones (TG) site	TG site optimized	TG site IMTA
Model inputs			
Farm area (m ²)	60 000	60 000	60 000
Seeding density (tonnes TFW)*	12	210	12
Culture period (days)	395	395	395
Seed weight (g)	1.2	1.2	1.2
Harvest weight (g)	90	90	90
Natural mortality (per year)	0.35	0.35	0.35
Model outputs			
Production			
Total physical product (TPP) (tonnes TFW)	139.6	952.5	154.0
Average physical product (APP)	11.6	4.54	12.8
Environmental impact			
Deposition of POC (kg/m ² /year)	7.64	10.44	9.96
Sediment organic enrichment (% POC/year)	6.88	9.03	8.66
Sediment accretion rate (mm/year)	7.73	10.57	10.08
Carbon removal (kg C/year)			
Phytoplankton removal	8 860	117 015	8 966
Detritus removal	60 000	866 008	62 086
Nitrogen removal (kg N/year)			
Phytoplankton	-1 378	-18 202	-1 395
Detritus	-9 333	-134 712	-9 658
Excretion	576	8 129	587
Faeces	4 942	70 997	5 108
Mortality	81	1 138	83
Mass balance	-5 111	-72 651	-5 274
Population equivalents (PEQ/year)	1 549	22 015	1 598
Income**			
Shellfish farming (1000 €/year)	645.2	4 400.6	711.4
Nitrogen removal (1000 €/year)	46.5	660.5	47.9
Total (k €/year)	691.7	5 061.0	759.4***

Terminology: particulate organic carbon (POC).

* TFW = total fresh weight (with shell).

** Price of input (cost of seed): 1 €/kg, price of output (sale): 5 €/ kg.

*** Does not include revenue from finfish culture.

Source: Silva (2009).

Optimum profit is achieved with a substantially higher stocking density (210 tonnes TFW), at a decreased, but still very attractive, APP of 4.5. Negative effects on the sediment show an increase of the order of 50 percent, and there is a marked reduction (about 25 percent) in water column chlorophyll and organic detritus. Farmers often strive to achieve maximum production (i.e. by maximizing income), which can be well beyond the optimum profit point, providing a diminishing return on investment and greater environmental damage.

The TPP of 139.6 tonnes shown in the standard model (Table 8, column 2) is distributed over three 2 ha sections, which show progressively lower yields due to food depletion (40 percent, 33 percent and 27 percent, respectively from upstream to downstream). Fish cages were added in the two downstream sections of the farm (five cages with 1 000 fish in each section) to simulate an IMTA scenario (Table 8, column 4).

The particulate organic material from fish culture improves the overall yield by 10 percent and increases the APP to 12.8. The combined finfish production and increase in shellfish yield provides a supplementary source of revenue to the farmer, at a small cost in terms of increased biodeposition. The shellfish additionally provide an important environmental service by filtering a part of the uneaten food and solid waste from the finfish culture, which would otherwise potentially lead to organic enrichment of underlying sediment.

Relevance of virtual technology and decision support for management

The modelling system combines hydrodynamics, physiology and population dynamics, water quality and eutrophication models that together produce the outputs shown in Table 9.

All of these outputs are valuable in informing, siting, licensing and operating shellfish and finfish farms, both from the production angle and with respect to environmental effects.

TABLE 9
Outputs and applications of FARM

Output	Applications
Harvestable biomass over the cultivation period	Simulation of potential harvest; optimization of harvest timing; changes of seed density, mortality, food supply, etc.
Marginal analysis of production	Determination of optimum profit structure with respect to seeding. Determination of APP and marginal physical product (MPP)
Release of dissolved and particulate matter	Determination of biodeposition, potential consequences for sediment oxygen demand
ASSETS eutrophication model based on inflow & outflow water quality	Effect of the farm on water quality – shellfish farms tend to improve water quality, finfish farms have the opposite effect. Simulation of combinations in IMTA
Mass balance for carbon & nitrogen	Establish the carbon footprint of a farm, determine the role of shellfish farms in reduction of eutrophication symptoms, & the farm value for nutrient credit trading in ICZM

Source: Silva (2009).

Dynamic models provide a number of advantages over more traditional approaches, e.g. by explicitly simulating extreme events such as mortality due to oxygen stress in intertidal areas or contextualizing biodeposition from a farm in the light of natural patterns for the area. Rich data sets will improve confidence in model outputs, but even in data-poor contexts, this kind of screening model can support the licensing process, assist with farm financing and help managers decide on acceptable environmental trade-offs.

Case study 6: Welfaremeter

(Source: Stien *et al.*, 2008a,b; Stien, Kristiansen and Torgersen, 2010)

Objectives

Although a sea cage can contain fish worth over a million euros, the monitoring of the cage environment and fish behaviour is typically kept at a minimum. The reasons for the low monitoring level are both lack of suitable monitoring equipment and lack of computer systems for handling and interpreting large amounts of data. The Animal Welfare Group at the Institute of Marine Research (IMR – Norway) addressed this deficiency by developing a system for monitoring of cage environment, fish behaviour and automatic assessment of fish welfare in aquaculture sea cages.

The system is called Welfaremeter (Figure 9) and began as part of the EU project 022720 FASTFISH and the RCN project 179878 Velferdsmåler and is now continued in the RCN project 190259 WELFARE-TOOLS (W-T). W-T is also funded by The Fishery and Aquaculture Industry Research Fund (FHF) and Nord-Trøndelag Fylkeskommune.

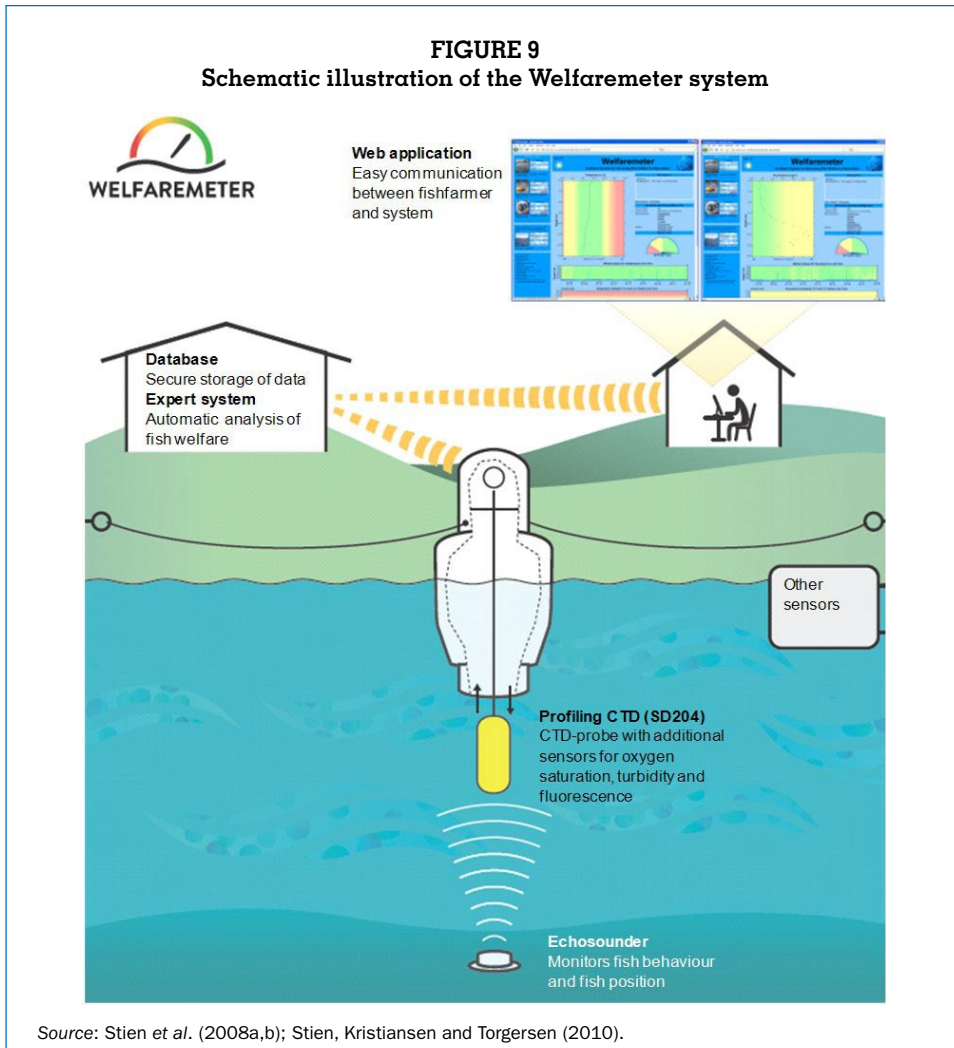
The prototype version of the system has been tested for two years in a commercial salmon farm, with promising results, and is now moving from prototype to a finished product. This second generation of the Welfaremeter is scheduled to be tested at two commercial farms from June 2010.

Target audience

The target audience includes all stakeholders in the fields of aquaculture production, management, research and policy implementation. Data from the system can also be part of surveillance of coastal waters.

Geographic area and scale of analysis

The first versions of the Welfaremeter are developed for salmon aquaculture in Norway. After the initial test period, there are plans to make the Welfaremeter available to other countries and to be extended to also cover other species (e.g. cod and seabass). If the system is adopted by the aquaculture community, it will provide data from a range of different sites on a continuous basis.

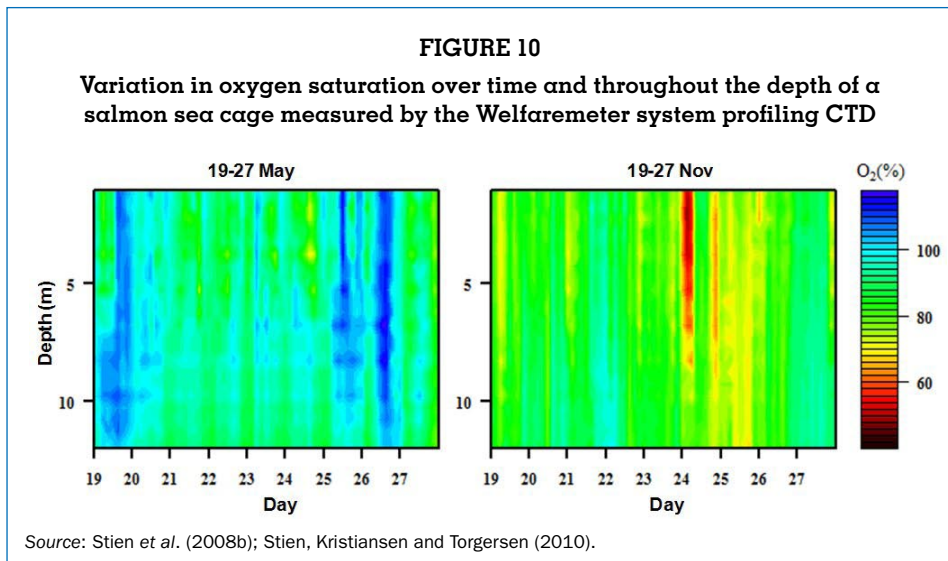


Analytical framework and results

The Welfaremeter is a collection of products that together document and analyze the conditions in a sea cage. These products include different measuring systems such as profiling conductivity, temperature and depth (CTD) instruments and echosounders, a database for safe storage of the data, an expert software program for analysis of the data, and an Internet application for easy viewing of the data and the results from the expert software.

Profiling CTD

Several studies show that conditions in a sea cage can vary with season, during the day and throughout the water column (e.g. Johansson *et al.*, 2007; Oppedal, Dempster and Stien, 2011).



These studies also show that measuring water quality outside a sea cage provides limited information of the environment experienced by the fish; e.g. Vigen (2008) observed highly variable and minimum 30 percent oxygen saturation inside a sea cage, even though the oxygen saturation outside the sea cage was near 100 percent. In consequence, it is necessary to measure the environmental conditions frequently inside a sea cage, and for the entire water column. A central component of the WelfareMeter is therefore a buoy (APB505, SAIV AS, Norway) with a profiling CTD. The buoy winches the CTD up and down in the sea cage at predefined intervals, measuring temperature, salinity, oxygen, fluorescence, and turbidity for the entire water column of the sea cage (Figure 10).

Echosounder

In cages with a clear stratification in water quality, farmed salmon position themselves in order to be close to their optimum environment (Johansson *et al.*, 2006; Oppedal, Dempster and Stien, 2011). Atlantic salmon have, for instance, been observed to prefer temperatures between 16 and 18 °C within a range of 11 to 20 °C (Johansson *et al.*, 2006). By including echosounder data, it is possible to know the water quality actually experienced by the fish, thus providing more accurate input to the expert software's models for fish growth and fish welfare (see below). Furthermore, if the fish position themselves at suboptimal water quality, this may be an indicator of disease or an immune-compromised state. The expert system compares the experienced and expected swimming depths as a behavioural indicator of the well-being of the fish. As an example, lack of activity towards surface feeding events may indicate poor welfare (Juell *et al.*, 1994).

Database, expert software and Internet application

The data from the different measuring systems are automatically stored in a central database. When new data arrive in the database, they are analyzed by the expert software. In addition to looking for abnormal vertical position (see above), the software uses data on the water quality to calculate a welfare index from 0 (terrible welfare) to 100 (excellent welfare). This index is based on modelling of metabolic scope (the capacity of fish to extract oxygen from the water beyond their basic needs) and is a measure of how much stress the fish can tolerate.

Relevance of virtual technology and decision support for management

The fish farmer can use the welfare index when managing meal times, feed amounts and to decide if operations (e.g. cleaning of the nets) can be performed or should be postponed. Both the incoming data and the results from the expert system are shown in the Internet application (www.imr.no/welfaremeter).

During the summer of 2010, the Welfaremeter system was tested at two different commercial sites along the coast of Norway. The goal was both to test the robustness of the different parts of the Welfaremeter system and to evaluate and improve the expert software. The expert software should be able to give the fish farmer daily information to improve fish welfare and hence the productivity of the fish farm. Additional data sources will be added as manual input via the Internet application, e.g. data from a probe that measures water quality outside the cage, and SmartTag. SmartTag is a system developed by Nofima Marin and Thelma AS (Norway) that registers breathing patterns of individual fish.

Onsite data acquisition systems like the Welfaremeter have a great potential in integrated decision-support tools in order to increase dynamic response and efficiency. The Welfaremeter is intended to be integrated into the AkvaVis tool (see Case study 3).

Case study 7: Shrimp pond culture (POND)³

Objectives and target audience

The Pond Aquaculture Management and Development (POND) model simulates individual growth (Franco, Ferreira and Nobre, 2006) and population dynamics of cultivated penaeid shrimp. Additionally, it fully integrates the relevant components of water and sediment quality (e.g. Di Toro, 2001; Burford and Lorenzen, 2004; Simas and Ferreira, 2007; Vinatea *et al.*, 2010), food decomposition, oxygen

³ Presentations by C. Zhu, J.G. Ferreira, M. Donato, A. Hawkins, X. Yan & A.Nobre on *LMPrawn – a model for management of cultivated penaeid shrimp* presented at ERF2007, Providence, Rhode Island, USA, 4–8 November 2007 and by C. Zhu on *Application of a shrimp farm management model to three types of shrimp farms in South China* presented at the Trilateral Symposium on Aquaculture Science among China, Japan and Korea, held in Guangzhou, China. October 22, 2009.

balance (e.g. Boyd, 1998; McGraw *et al.*, 2001; Zhang *et al.*, 2006) and effluent discharge. The economic aspects of the shrimp culture cycle (e.g. Kam, *et al.*, 2008) are also considered. The model is designed for shrimp pond aquaculture management, and has five main uses: (i) prediction of production and feed requirement; (ii) optimization of seeding size and culture period; (iii) optimization of farming methods (e.g. monoculture or IMTA with bivalves such as razor clam); (iv) analysis of impacts on water quality, important for certification and sustainable development (Boyd, 2009); and (v) profitability assessment, including evaluation of externalities. POND is currently applicable to the whiteleg shrimp (*Litopenaeus vannamei*) and Indian white prawn (*Fenneropenaeus indicus*), and IMTA of shrimp with other species (e.g. tilapia, bivalves) may also be simulated.

Geographic area and scale of analysis

POND has been successfully applied to shrimp farms in Venezuela and southern China. The model is designed for use by farmers and managers, at the scale of individual production ponds.

Analytical framework and results

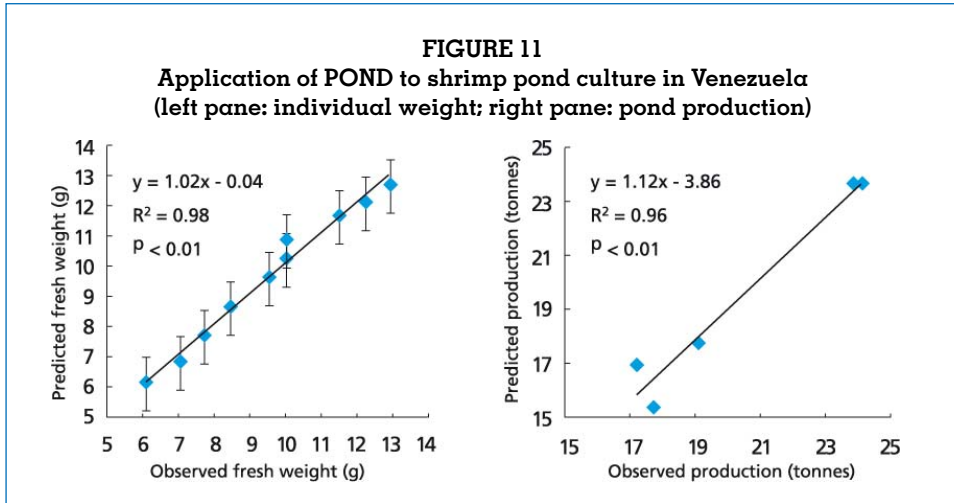
POND computes individual growth of penaeid shrimp from the juvenile stage to the end of the culture cycle.

Shrimp larval stages (nauplius, zoea and mysis) have a very short duration of less than three weeks, and were not included. The growth model simulates five physiological processes: ingestion, assimilation, elimination of faeces, respiration and reproduction, and is forced by food availability, water temperature and dissolved oxygen. These are used to determine scope for growth at the population level, by considering the transition of individuals across an appropriate range of weight classes. Growth and mortality are combined in the population model, and allow the biomass of harvestable classes to be determined.

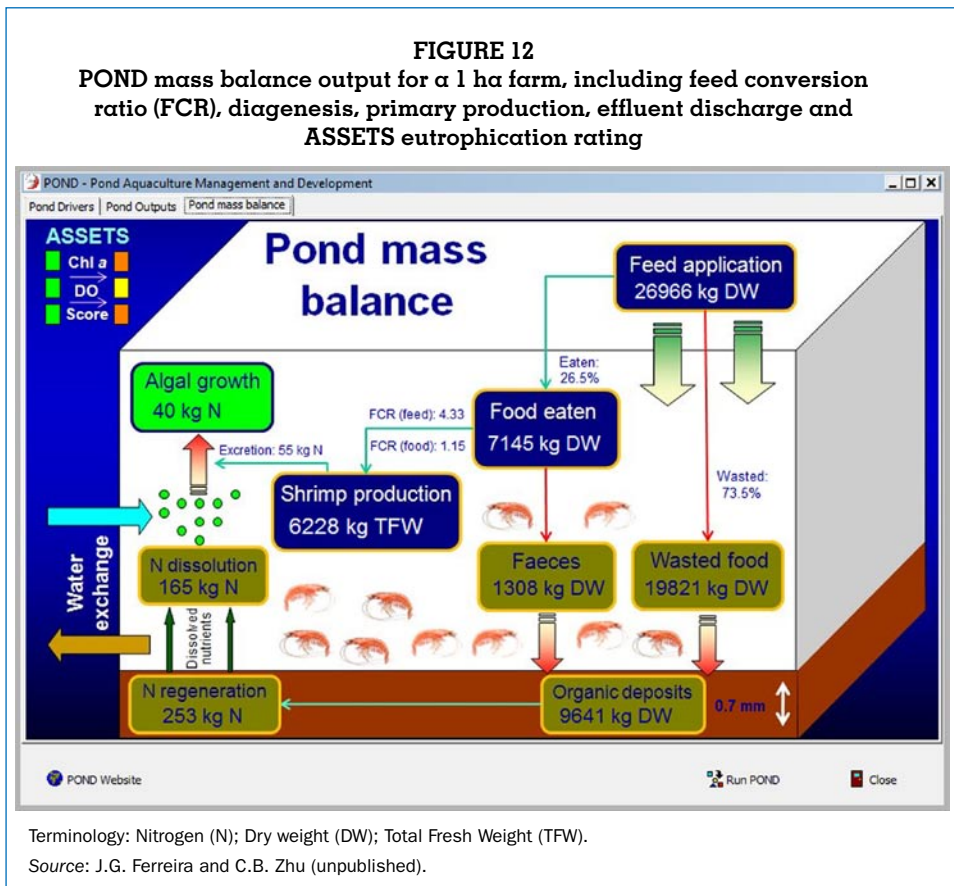
Validation results for *L. vannamei* individual growth and pond production for a farm in Venezuela are shown in Figure 11. The model is able to satisfactorily reproduce both the individual weight of the animals and the farm production, which suggests that it may be used for management purposes.

Relevance of virtual technology and decision support for management

This case study is the only example which focuses on land-based pond culture, a very important component of aquaculture in Asia and Africa. The model explicitly simulates environmental effects, which allows the industry in developing nations to address certification issues and to determine the environmental footprint of shrimp farms, both with respect to discharge and sustainability of the ponds themselves.



A simple version of the model may be run online at www.pondscale.com for assessment of production only, and a more detailed console version allows users to examine various aspects of the culture cycle, including waste feed, pond eutrophication and oxygen balance. Figure 12 shows the mass balance output for a simulation of whiteleg shrimp cultivated for a period of 110 days;



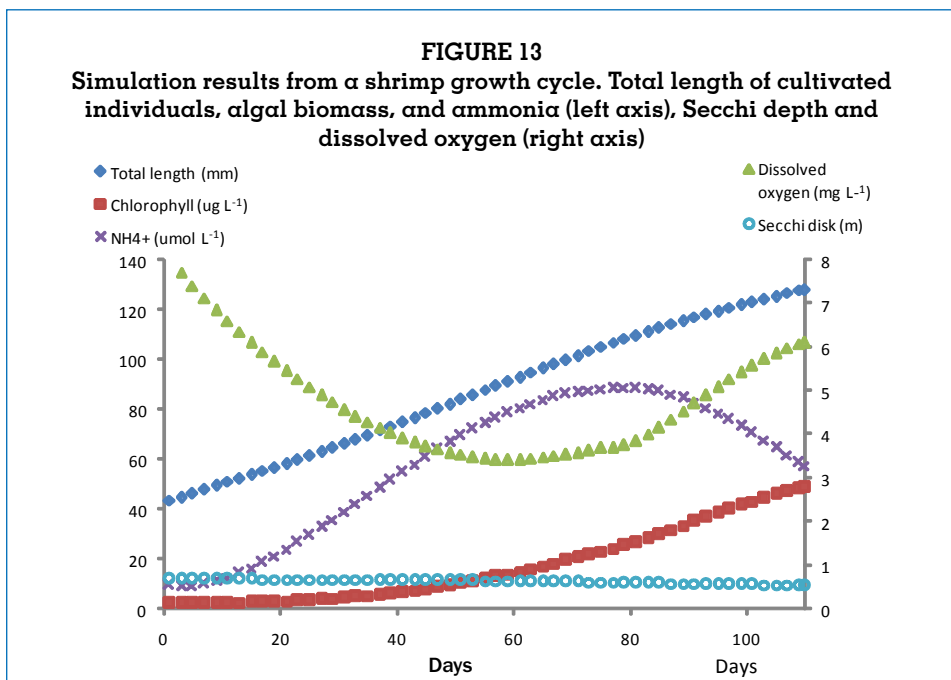
food is administered on demand, and simulates the use of trays to inspect and adjust feed consumption by the animals, leading to a feed conversion ratio (FCR) of 1.7 and a minimal feed waste of around 11 percent.

Nitrogen supplied by excretory products from the shrimp and by sediment diagenesis drives algal growth, which in this example leads to a net primary production (NPP) of 46 kg of nitrogen over the culture cycle. POND constrains yield based on dissolved oxygen, which in the model conditions both individual growth (McGraw *et al.*, 2001) and population mortality (Zhang *et al.*, 2006).

The mass balance in Figure 12 accounts for water renovation at a daily renewal rate of 3 percent of pond volume and determines the outflow of ammonia, particulate nitrogen (in phytoplankton) and chlorophyll over the culture period. The waste products discharged from farms correspond to a production cost which is not internalized, needs to be evaluated as part of an ecosystem approach to aquaculture, and will increasingly be required for product certification in western markets. Currently, pond production in the United States of America already requires a National Pollutant Discharge Elimination System (NPDES) permit (Boyd, 2009).

Over 60 kg of nitrogen (mostly dissolved, but also as algae) are discharged to the environment, roughly 20 population-equivalents per year for the 110 day cultivation cycle. The cost of abating that nitrogen discharge would be about USD800 (Lindahl *et al.*, 2005).

Figure 13 shows the model outputs for five environmental variables over the culture cycle. At harvest time, the total length of an individual is about 13 cm, for



an individual weight of 12.9 g. Chlorophyll increases more rapidly in the second half of the cycle, as more dissolved nitrogen becomes available in the pond, and the higher concentration of particulates reduces the Secchi depth from 67 cm at the start of the culture to a final value of 53 cm.

The percentile 10 (P_{10}) for dissolved oxygen in this example is 6.2 mg/liter in the inflow and 3.5 mg/liter in the pond and outflow. If the primary production component is switched off, the P_{10} in the pond falls to 2.7 mg/liter (40 percent saturation) and the total yield is reduced by 57 percent to 2 700 kg. This can be offset by increasing aeration (also simulated in POND), but with a corresponding increase in production costs: over USD800 if aerators are always running, about USD100 if switched on only at dusk whenever dissolved oxygen falls below 50 percent saturation.

The percentile 90 (P_{90}) for ammonia increases from 9.6 mmol/liter in the inflow to 88.2 mmol/liter in the pond, and the corresponding P_{90} data for chlorophyll are 8.3 and 40 mmol/liter, respectively (Figure 13). These values are in the ranges reported by Burford and Lorenzen (2004) for the late stages of giant tiger prawn (*Penaeus monodon*) culture in Australia (~1 mg/liter ammonia and 50–100 mg/liter chlorophyll). If water renewal is not used, NPP increases to 64 kg N and the chlorophyll P_{90} in the pond is 64.4 mg/liter, which corresponds to an ASSETS grade (Bricker, Ferreira and Simas, 2003) of hypereutrophic.

Future developments include the addition of stochastic functions to examine the relationship between stress (e.g. induced due to hypoxia), and the onset of diseases such as white spot syndrome (WSS) (Guan, Yu and Li, 2003).

Salient and emerging issues and the way forward

The final part of this review places virtual technology in the context of the Bangkok Declaration and ensuing developments, and discusses key aspects of the future of this technology in supporting decision-making for aquaculture in the coming years, in the context of EAA.

Implementation of the Bangkok Declaration

Background

The Conference on Aquaculture in the Third Millennium (the Bangkok Conference on Aquaculture) was held in February 2000 in Bangkok, Thailand, for the purpose of developing a strategy for aquaculture development in the next 20 years. It was attended by 549 participants representing all stakeholder groups in aquaculture, from more than 200 organizations and 66 countries in Asia, Africa, Latin America and the Caribbean, Europe, the former Soviet Republics, the Near East, North America and Oceania. The Conference crafted the document *Aquaculture Development Beyond 2000: the Bangkok Declaration and Strategy*, which has been published by the Network of Aquaculture Centres

in Asia-Pacific and the Food and Agriculture Organization of the United Nations (NACA/FAO), and addresses the role of aquaculture in alleviating rural poverty, improving livelihoods and food security, and maintaining the integrity of natural and biological resources and the sustainability of the environment. The strategy comprises 17 elements that focus on measures that governments, the private sector and other concerned organizations can incorporate into their development programmes for the aquaculture sector. It highlights the need for regional and interregional cooperation to assist in its implementation (NACA/FAO, 2000).

Implementation

The Bangkok Declaration (NACA/FAO, 2000) aims to ensure the sustainable development of aquaculture over a ten-year horizon. The key elements of the Bangkok Declaration and Strategy have remained relevant and timely ten years after the issue of the document in 2000, but the diversity of the aquaculture sector has further increased since the conference took place in 2000. Of particular significance are the continuing advances in information and communications technology (ICT) which are giving a tremendous boost to the industry. None of the 17 strategic elements of the Bangkok Declaration made explicit reference to the use of virtual technology, since this area was only starting to emerge. However, it is clear that virtual technologies and decision-support tools for novel management are directly related to a number of strategic elements such as applying innovations in aquaculture, investing in research and development, and improving information flow and communication.

A number of specific actions and trends are proposed and discussed in the final part of this review, but in order to ensure that these technologies do not exacerbate the divide among nations, a brief overview of (i) constraints to application and (ii) success stories needs to be made.

Constraints in developing countries and actions needed

Prioritization

Aquaculture has special importance to developing countries, where it is not only critical in supporting healthy food provision for often large populations, but is also an important source of income for local communities. Developing countries often have a comparative advantage (as opposed to an absolute advantage) in aquaculture production, often due to climatic factors, i.e. it makes sense economically for resources to be utilized in aquaculture production because these nations can do this at a lower cost than developed countries. This may be of particular importance to developing countries, perhaps even more so than food provision and income, since these are consequences of economic incentives due to land availability, lower labour costs and favourable climatic conditions.

Which developing countries and which environments should be the priorities for the implementation of virtual technologies? From an EAA perspective, those

making the most impact on the environment are the most likely candidates. One approach aimed at identifying such countries used FAO production statistics at country-environment level (freshwater, brackishwater and marine) to estimate the intensity at which aquaculture was practiced in each of those environments (Kapetsky, Aguilar-Manjarrez and Soto, 2010).

Which tools will be most appropriate to disseminate in a given country? A knowledge of the species being cultured can reveal the production systems and their associated kinds and magnitudes of impacts in a very general way. This review tabulates and illustrates many of the tools; thus, the approach outlined above can be refined to focus more closely on virtual technology needs by considering the potential impacts by species and culture systems in countries in which production data by species are reported.

Should dissemination of virtual technology tools be passive (e.g. packages freely accessible via the Internet) or active (e.g. training courses and workshops by region or by country)? Bearing on this decision, a fundamental question is: “What is the capacity (equipment, levels of technical competence) to responsibly and efficiently utilize the tools?”

In order to serve either of these avenues of dissemination, it is essential, above all, to establish the technical capacity, level of interest and financial commitment of the audience and the status of the Internet as a communications and data pipeline for technical support in each country. The focus should not be on developing countries alone for the reasons that: (i) virtual technology specialists in developed countries may be in a position to partner with FAO’s Fisheries and Aquaculture Department’s Aquaculture Service (FIRA) to aid dissemination; and (ii) companies established in developed countries often have aquaculture operations in developing countries, and could therefore also find it in their interest to offer support to virtual technology.

Application and challenges

Progress in the use of virtual technology in China, the world’s largest aquaculture producer, illustrates some of these challenges. In recent years, continuing industrialization and population growth in the coastal areas of China have led to dramatic conflicts among aquaculture, industry, environment and human life, and the demand for sustainable aquaculture development and ICZM has become increasingly urgent.

Virtual technologies such as remote sensing and modelling for aquaculture management and ICZM were introduced to China during the late 1990s through a series of collaborative projects with Europe and North America. Knowledge transfer through these international programmes led to the application of some of the tools referred to previously, e.g. the MOM model for Sanggou Bay (Zhang *et al.*, 2009), the EcoWin2000 and FARM models in Sanggou Bay and Huangdun

Bay (Ferreira *et al.*, 2008a), and the POND model for shrimp farms in Zhejiang and Guangdong provinces. However, most of the virtual technology applications for aquaculture management in China are still limited to the research technology development (RTD) level, and few have been used in actual management practice. Nevertheless, the SPEAR project succeeded in actively involving stakeholders from farming cooperatives and local administrators in the iterative process of scenario definition, model application, and review and interpretation of outcomes, using a driver-pressure-state-impact-response (DPSIR) framework. Currently, a few influential stakeholders such as large aquaculture companies (e.g. Zhangzi Dao Co. Ltd.) and high-tech aquaculture feed companies (e.g. Haid Co. Ltd.) have begun to apply GIS, remote sensing and modelling tools, either solely or in collaboration with academic institutions (Zhang, Fang and Wang, 2008).

Conclusions

Virtual technologies have an important role to play through the use of (i) GIS, remote sensing and ecosystem-scale models to determine site suitability and carrying capacity; (ii) farm-scale tools to support licensing, EIA and optimization of production; or (iii) sensors for data acquisition for monitoring and modelling.

As illustrated by the case studies presented in this review, some of the key benefits of using virtual technology and decision-support tools for aquaculture management include: predictive capability and the ability to run “what-if” scenarios, simulation of environmental effects to quickly examine development scenarios, near real-time scenarios of environmental impacts of aquaculture at both the farm and bay scales, stakeholder consultation and participation for development of an efficient and auditable tool(s), integration of ecological and economic models to provide estimates of the medium to long-term profitability of IMTA, and use of dynamic models to simulate extreme events such as mortality due to oxygen stress in intertidal areas or excess biodeposition from a farm relative to natural sedimentation patterns.

A positive trend is that virtual applications for aquaculture are becoming broader in scope to the point that multiple issues are more frequently being addressed by any single application; for example, case studies illustrate the incorporation of multiple species and multiple models at different scales, including economic models, and varied temporal scales for the simulation of consequences of management options.

In the future, virtual technologies will play an increasingly important role in the prediction of potential aquaculture siting and production, environmental impacts and sustainability. The next decade will bring about major breakthroughs in key areas such as disease-related modelling, and witness a much broader use of virtual technology for improving and promoting sustainable aquaculture in many

parts of the world. Even if attractive and promising, virtual technology requires adaptation to local conditions and compromises with respect to ease of use, data requirements and scientific complexity.

An enabling environment is crucial to link data/model requirements and current capacities (e.g. human resources, infrastructure, finances) for the development and/or use of virtual technologies at the national and/or regional level so that capacity-building activities can be initiated.

Summary of lessons learned and key recommendations

The aquaculture industry is going to be affected by many different issues and trends over the coming years, often operating concurrently, sometimes in unexpected ways, and producing changes in the industry that may be very rapid indeed: without a doubt virtual technology and decision-support tools will play an important role in addressing many of these, and will therefore underpin many elements of the *Bangkok Declaration and Strategy*. Some of the directions and challenges are listed below:

- Innovations will drive aquaculture development as new technologies such as virtual technologies become more widespread and aquaculture production becomes more and more competitive.
- Information exchange and networking are going to accelerate the use of virtual technology and decision-making for problem solving to support industry growth. Web-based access to real-time information will further accelerate this growth.
- Links between industry and research centers will need to be more effective to create a genuinely objective-led demand for virtual technology-driven RTD approach to sector development.
- There will be a need to strengthen collaboration among countries, mainly through educational and research programmes (e.g. interregional collaboration between Europe and developing countries).
- Strategic alliances will need to be reinforced or created for the implementation of virtual technology for aquaculture in developing countries; for example, FAO and WorldFish Center are working in many of the same target countries, and this could facilitate the transfer of research outcomes on virtual technology to end users. The same applies to collaborative research with third countries mediated e.g. by the EU, the United States of America and Canada.
- Many virtual technology tools will need to be more production and management-oriented; and even if attractive and promising, these tools will have to be adapted to local realities and conditions to really become useful (and used) in the future. This requires a compromise with respect to ease of use, data requirements and scientific complexity. Many such tools will evolve from service to product, requiring academic developers to accept a loss of control in conditions of application, as a natural trade-off (and inherent risk) of product maturity.

Finally, we provide some examples of key thematic and technical areas where virtual technologies for aquaculture are currently incipient, and expected to develop strongly in the next decade or so, integrating and complementing existing tools. This identification is based largely on gaps identified in this review.

Disease

Disease in cultivated species is a major source of concern, and is not as a rule predictable in the deterministic sense. A stochastic approach, based on risk and uncertainty analysis, will provide some measure of decision support, particularly where correlative approaches can be implemented, relating e.g. stress factors with disease outbreaks, such as reported by Guan, Yu and Li (2003) for WSS in penaeid shrimp. Statistical models based on the susceptible-infected-removed (i.e. recovered or dead) SIR approach (Anderson and May, 1979) have been used successfully to analyze furunculosis in chinook salmon (*Oncorhynchus tshawytscha*) (Ogut, Reno and Sampson 2004).

Only a few models have been developed to simulate pathogenic infections of shellfish with respect to physiology, e.g. Powell, Klinck and Hofmann (1996) for the American cupped oyster (*Crassostrea virginica*), but with widespread concerns about relaying, susceptibility and mortality, models focusing on a more mechanistic approach will undoubtedly appear over the next decade.

Risk assessments are under development for disease transmission in salmon aquaculture (mainly pancreas disease and salmon lice), based on hydrodynamics and risk of “water association” (e.g. the AquaStrøm project, developed by the Norsk Institutt for Vannforskning (NIVA, <http://niva.no>). Mechanisms such as pathogen survival and the role of vertical (vs horizontal) transmission are currently neglected, and thus in various respects this kind of work is at an early stage. The principle of zoning is currently a main management tool to establish “fire doors” to prevent or reduce the risk of infection among aquaculture areas.

Increasing emphasis is being placed on the use of real-time data acquisition combined with models for real-time analysis and short-term prediction of animal welfare, and it is expected that such systems will become cheaper and more generalized, and that some of the indicators and trends will find an application at longer time-scales, albeit by means of a probabilistic approach.

Other possibilities include the use of sentinel fish in the farmed population, fitted with real-time physiological sensors and data transmitters, as such technology becomes further miniaturized and increasingly cheaper (J. Bostock, personal communication, 2010).

Harmful algal blooms

This is another area where little predictive capacity exists, except in the short term through the use of operational oceanography, relying on bloom

identification and tracking. Management is at present reactive, and modelling of appearance and development of such blooms is in its infancy, due to the lack of an appropriate paradigm. Sensors such as targeted RNA probes (e.g. Greenfield *et al.*, 2006), integrating hand-held devices, or potentially deployed *in situ* and used in a networked framework will both help in early detection and management and contribute to the understanding of the underlying triggers. Considerable developments are also expected in remote sensing algorithms able to discriminate (at least) between HAB and non-toxic blooms (S. Bernard, personal communication, 2010).

Certification and traceability

The arrays of sensors that can be deployed at the farm scale to enable coupled monitoring and modelling, as exemplified in the Welfaremeter case study, additionally have an important role to play in both product certification and traceability. The number, reliability and accuracy of underwater sensors will increase and the cost will decrease, both with technological developments and market growth. Real-time data acquisition and interpretation will make it possible for consumers to visualize the whole “womb to tomb” cycle of an aquaculture product.

For instance, a batch of oysters may be “bar-coded” on a Website to reveal the origin of seed and the entire environmental interaction over the culture period, including metadata and measured data on water quality, HAB events, condition (meat ratio) of the animals, and impact on their environment, e.g. in terms of reduction of eutrophication symptoms through the indirect removal of nitrogen and phosphorus, and the addition of particulate organic material due to biodeposition. Such sensors will typically be queried at a subhourly frequency, particularly if they are also used for welfare monitoring; this will easily allow importers, health inspectors or consumers to perform verification and certification, and will provide an important contribution to both food safety and environmental awareness. For the farmer, the existence of this kind of integrated “taxi-meter” will also help improve various aspects of culture practice and increase attractiveness of the business model to the key sector of insurance. For the mainstream consumer, it is likely that such data will need to be presented in a comprehensible format, e.g. in the form of a few indicators.

Modelling with data scarcity

It is an axiom of modelling that good data are required to support acceptable predictions. The production of high-quality data, with appropriate spatial and temporal resolution, is expensive, and frequently beyond the scope of developing countries, except on a fairly limited scale. This, together with an often fragmented approach to the study of interacting ecosystems, in many cases driven by institutional barriers, makes model application a challenge.

The *deus ex machina* approach to monitoring, i.e. data for data's sake, without an underlying set of hypotheses, frequently means that scarce resources are under or mis-utilized, ignoring key scales, processes and variables.

Improved mechanisms for data access, particularly remotely sensed data, together with models that deal with uncertainty and risk, will both contribute to conversion of sparse data into more meaningful information – although such an approach may be considered inappropriate in parts of the developed world, in many countries it will be a much better basis for decisions than the options that are presently used. In addition, it will promote a “virtuous cycle” towards more informed decision support, the use of better data and more sophisticated virtual tools.

Information technology

The last five years have seen a huge leap in various areas of distributed computing, all of which are expected to develop significantly in the coming years. Three examples are presented here:

- (i) The Web 2.0 phenomenon now provides a large diversity of community and corporation-based resources. This is exemplified on YouTube, where over 1 800 items currently exist for aquaculture, and around 20 for aquaculture modelling, including demonstrations of models such as Tropomod, developed by SAMS, Akvaplan-Niva, and partners from the Philippines for impact assessment of organic deposition (e.g. for tilapia ponds: www.youtube.com/watch?v=wwfqlueK3Kg).
- (ii) There is a strong trend towards the development and use of software as a service (SAAS), as exemplified e.g. by Google Apps, which rival traditional desktop applications; this is incipient in the aquaculture world, but can be seen e.g. in the WinShell application (<http://longline.co.uk/winshell>), which allows users to simulate individual shellfish growth on line. Central to the development of this kind of application are rich Internet applications (RIA), which provide a full user experience and are an area of rapid growth (Anderson, McRee and Wilson, 2010).
- (iii) Mobile computing is increasingly ubiquitous, and it is now possible to use GIS on many hand-held devices, as illustrated in Figure 14, which shows a large tilapia farm on Hai Ou (Seagull) Island on the Pearl River, China. The trend towards increasing use of such devices, including for various real-time applications in aquaculture management, will undoubtedly increase. In parallel, the concept of the stand-alone server is rapidly shifting towards cloud computing, which will tend to make the circulation of data both easier and cheaper. Both of these elements will contribute to bridge the gap between richer and poorer nations in the access to information technology.

There is a need for tools and models that can forecast the future of aquaculture holistically, that is, with natural, socio-economic and administrative-policy realms integrated across temporal and spatial scales. This holistic approach can be implemented, but will require a commitment to well-coordinated multidisciplinary teamwork ranging from the global scale right down to the farm scale. As for many other areas of human endeavour, virtual technologies show enormous potential to inform and guide the future development of aquaculture towards a world which is more socially responsible, more equitable and more sustainable.

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FIGURE 14
Aquaculture (tilapia) geographic information system (GIS) displayed on a mobile platform (southern China)



Source: J.G. Ferreira, unpublished.

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Protecting small-scale farmers: a reality within a globalized economy?

Expert Panel Review 6.1

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Abstract

Aquaculture is still the fastest-growing food-producing sector and plays an important role in enhancing global food security and alleviating poverty. Tens of millions of people are engaged in aquaculture production, the majority of whom are small-scale farmers who have limited resources and are faced with difficulties due to increasing globalization and the resultant trade liberalization of aquaculture products. Despite these challenges, small-scale farmers remain innovative and continue to contribute to global aquaculture production.

KEY WORDS: *Aquaculture, Better management practices, Small-scale farmers, Small-scale aquaculture.*

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Introduction

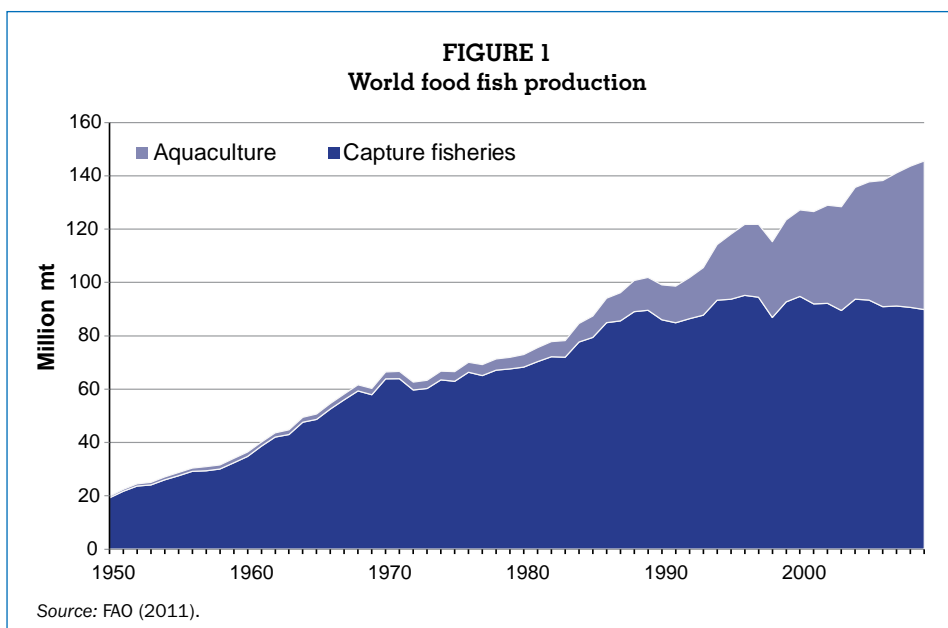
Although the Bangkok Declaration and Strategy (NACA/FAO/DOF, 2000) made no specific mention of the importance of protecting small-scale aquaculture against increasing market-driven forces and challenges, it clearly recognized that the development of small-scale aquaculture would require significant public-sector support. It also stressed the importance of providing longer periods of support for poorer target groups and empowering them to actively participate in policy formulation and decision-making.

Enhancing food security and alleviating poverty are major and complementary global priorities, and aquaculture has a special role to play in achieving these objectives. This is because, firstly, fish is a highly nutritious food that forms an essential, if not indispensable, part of the diet of a large proportion of the people in developing countries. Secondly, while aquaculture contributes to the livelihoods of poor farming households, particularly in areas of Asia where it is a traditional farming practice, there is a huge, unfulfilled potential in most countries, as aquaculture is a relatively recent and underdeveloped sector as compared to agriculture and animal husbandry. Declining wild catches in some countries are also driving interest and investment in aquaculture to plug supply gaps at all levels, from household to national levels. Aquaculture can directly and indirectly improve food security and provide various entry points for contributing to sustainable livelihoods for the poor. The Bangkok Declaration and Strategy further stated that strategies are required to make people the focal point for planning and development for such programmes and to integrate aquaculture into overall rural development programmes.

Aquaculture and people

Aquaculture is still the fastest-growing food-producing sector in the world, and over 80 percent of global aquatic produce originates from Asia. Aquaculture now accounts for about 48 percent of the global food fish supplies (Figure 1) and its contribution is expected to surpass 50 percent by 2012. Aquaculture products are now recognized as globally traded commodities. In the coming decades, aquaculture is expected to bridge the global aquatic food supply and demand gap created by stagnant capture fisheries production, in order to feed the continuously growing human population (FAO, 2011).

While food supply and economic output are primary drivers for aquaculture development, the role of aquaculture's contributions to food security, employment creation, income generation and the empowerment of women is an important policy consideration, particularly in the case of developing countries facing the challenges of reducing poverty, increasing rural employment and improving livelihoods. Fisheries and aquaculture provide direct and indirect livelihood support to millions of people around the world. In 2008, out of an estimated



44.9 million people who were directly engaged full time or part time in capture fisheries or aquaculture, an estimated 10.7 million were involved in aquaculture, or about one-quarter (24 percent) of the total number of workers. Of the 44.9 million people employed in capture fisheries and aquaculture, 12 percent were women (this figure is almost certainly an under-estimate). The majority of fish farmers are in developing countries, mainly in Asia, which accounted for almost 96 percent of all people employed in the sector (FAO, 2011).

In addition to fishers and fish farmers involved in direct production of fish, a large number of people are engaged in other ancillary or secondary activities. While no official data exist for such groups of people, it has been estimated that fishers, aquaculturists and those supplying services and goods support the livelihoods (including dependent family members) of a total of 540 million people, or 8.0 percent of the world population (FAO, 2011). Women make up a significant proportion of this group.

According to a recent ad hoc estimation of employment in world aquaculture by the Food and Agriculture Organization of the United Nations (FAO), it has been reported that aquaculture employs about 23.4 million full-time equivalent workers, which includes 16.7 million direct (about 1.2 percent of the population employed in agriculture worldwide) and 6.8 million indirect jobs. The global estimate for employment in world aquaculture was attempted only for 2005, as the most complete information was available for this year. Considering an average family size of five members, it can be inferred that aquaculture contributed to the livelihoods of about 117 million people or 1.8 percent of the global population. As expected, Asia accounts for more than 92 percent of total

employment. In terms of labour productivity, it is highest in North America and Europe, an indication that the sector in these regions is highly industrialized (Valderrama, Hishamunda and Zhou, 2010).

Aquaculture development today faces a number of serious challenges to meet the projected demand and indeed, to continue to provide such social and economic services. A number of over-arching external drivers are threatening the sector, and particularly small-scale stakeholders in poor and more vulnerable communities. These include increasing competing pressure on available land and water resources for expansion, pollution, climate change, natural disasters, HIV-Aids, and local risks associated with increasing globalization. The importance of small-scale aquaculture to the sector as a source of income, food and employment for many poor people is widely promoted and is generally considered to be highly significant, yet its significance cannot be truly estimated due to a lack of available and accessible data.

Small-scale aquaculture and globalizatio

Between 70 and 80 percent of the global aquaculture farmers are estimated to be small-scale farmers¹. This small-scale sector is especially important for rural development, employment and poverty reduction in developing countries. However, while this sector is socially and economically important and continues to remain innovative, for farmers growing some export products such as shrimp, it faces many constraints and challenges in integrating into modern supply chains and dealing with the changing market environment. Nevertheless, the domestic importance of small-scale aquaculture for many small-holders servicing local markets or growing fish as part of a household livelihood strategy, such farming remains highly significant (Belton *et al.*, 2011).

The past few decades have shown a clear growth in overall global food production; however, the per capita gross national product (GNP) increased only in the Organisation for Economic Co-operation and Development (OECD) countries and to a lesser extent in Eastern Europe and Asia. While the numbers of people in poverty have declined in East and South Asia, global poverty has certainly not been reduced, and eradicating poverty and hunger still remains the most challenging and fundamental global humanitarian task. It has been estimated that over one billion people currently live below the poverty line, perhaps having less than one meal a day (FAO, 2011).

¹ The term “small-scale farmers” is not well defined, but is considered here to encompass people involved in a spectrum of household-managed farming activities ranging from “subsistence” farming to more commercially oriented micro and small-scale enterprises. Small-scale farming may be characterized by smaller land area, being predominantly managed by families and having limited access to services. Small-scale aquafarmers are resource-poor individuals or groups of people involved in small-scale aquaculture production, i.e. having aquaculture production facilities and processes with small production volume, and/or relatively small surface area and typically lacking technical and financial capacity (see FAO, 2011 for further details).

Aquaculture has the potential to play a more important role in contributing to the daunting task of reducing global poverty through provision of nutritious food for the poor, as a source of livelihood for the many producers and people involved along the aquaculture value chain, and as a source of wider economic growth, stimulating growth in other sectors through production and consumption linkages.

The positive impacts of globalization include worldwide marketing of goods and services; increased economies of scale; and corporate governance of the industrial food production sectors taking advantage of inexpensive labour, capital and technology. There is, however, good evidence that while the industrial and corporate sectors continue to benefit from globalization, small-scale producers are slowly being pushed out of business due to competition.

The combined effects of trade liberalization and globalization have increased economic differentiation among communities and households. In addition, state withdrawal from agricultural marketing has contributed to a highly uncertain environment in which input and output prices are determined by the market, often favouring large-scale producers who are better equipped to manage price variability and/or absorb price shocks and to gain through efficiencies of scale in commodity production.

It is clear that increasing globalization and the resultant trade liberalization of aquaculture products is leading towards the marginalization and exclusion of individual small-scale producers, who face major challenges to remain competitive and to participate in modern value chains, globally. The situation is particularly serious in Asia, due to the large numbers of people involved, but the trend affects farmers across the aquaculture-producing regions. This is partly due to integration of production-distribution chains and coordinated exchange between aquaculture farmers, processors and retailers, and is evident in the higher-value internationally traded export species such as shrimp, although this trend is now also affecting low-value species such as catfish and tilapia in some countries.

Challenges facing small-scale producers

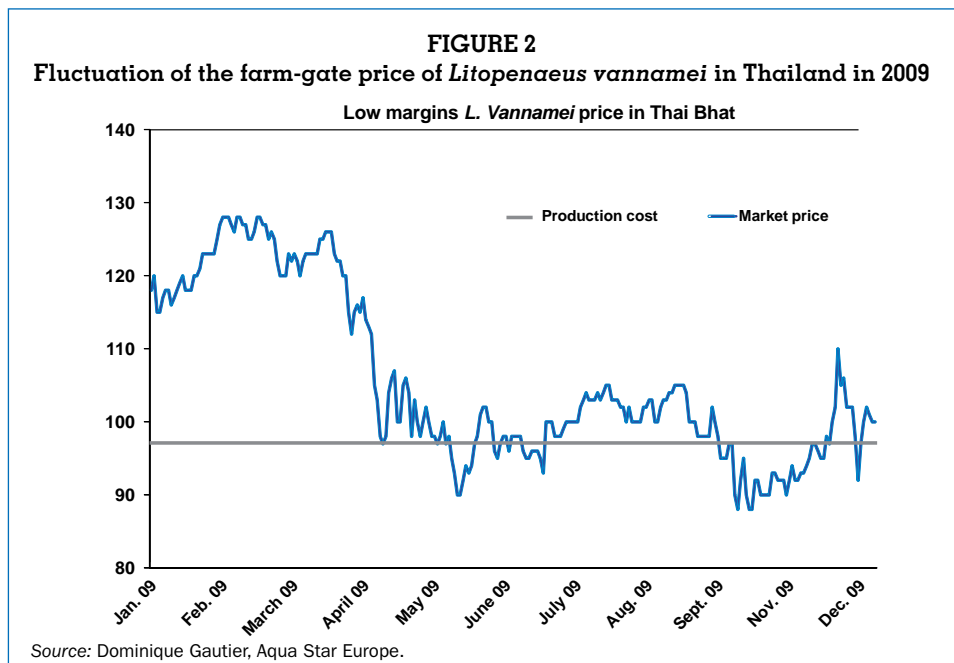
Small-scale producers face challenges related to the changing preferences of consumers for safer, healthier, better quality food produced in environmentally sustainable and ethical ways. This has resulted in increased demand for food safety and environmental standards, or “niche” products that have special characteristics based on their quality, farming practice and origin. These characteristics are strongly linked to how products are being produced rather than to the end product itself, thus, putting greater emphasis on traceability. Growing customer awareness has also led to the development of several aquaculture certification schemes, making it no longer enough for aquaculture

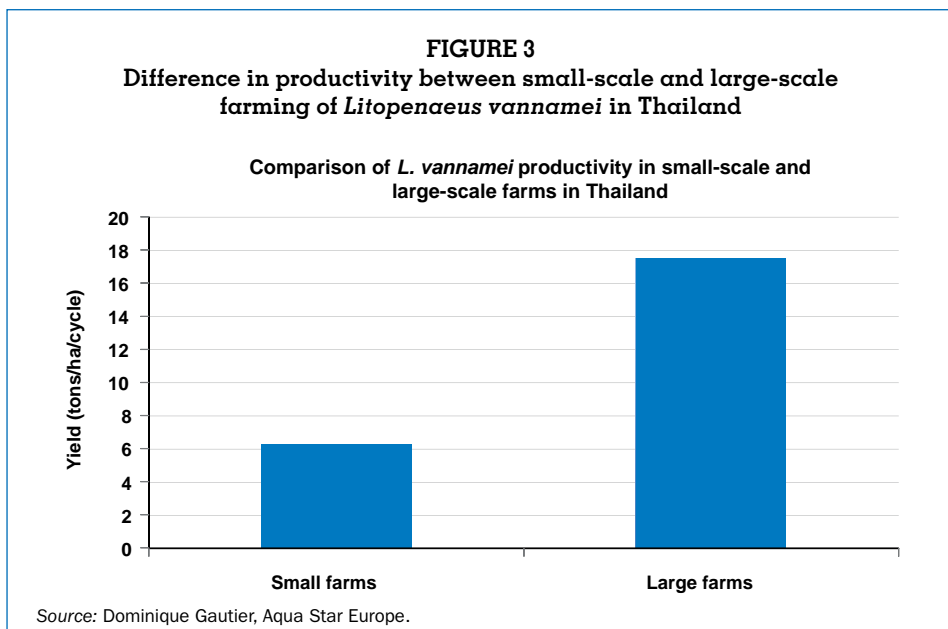
farmers to pay attention solely to efficient production. These increased demands for meeting food safety standards, traceability, certification and other non-tariff requirements are driving risks and costs down the market chain to the farmer, favouring medium to large-scale, capital-intensive operations that can afford such extra costs and excluding small-scale farmers who have limited resources and capacity to meet these requirements.

To remain competitive, there is a need to change the management of both large and small-scale producers. Large-scale farmers have a much higher adaptive capacity to benefit from such trends than do small-scale farmers. Small-scale aquaculture farmers are not only exposed to increasing market risks, but also face enormous constraints in accessing markets and services and integrating into modern supply chains. In many cases, they are ill-equipped to benefit fully from the new market environment and knowledge because of lack of public and private policy and services to support investment and change, resulting in potentially significant social risks for many rural producers.

If we take *Litopenaeus vannamei* (whiteleg shrimp) farming as an example, the market price fluctuates tremendously as production volume increases, thus making it difficult for small-scale farmers to make a profit from small-scale production. Figure 2 shows how the farm-gate price of *L. vannamei* in Thailand fluctuated in 2009.

Besides farm-gate price, there is a significant difference in productivity between small-scale farmers and large-scale corporate farms. In Thailand, the difference





in productivity between small-scale and large-scale farming of *L. vannamei* is almost three times (Figure 3). The low productivity of small-scale aquaculture producers compared to larger enterprises has also been noted in various studies (e.g. Brummet, Lazard and Moehl, 2008).

It is important to reiterate that improved market access remains very important for small-scale producers and for rural development in general. Markets can often seem to be part of the problem rather than part of the solution, and in the real world, markets do not function in the perfectly competitive way that they are shown to in neoclassical economic theory. In developing countries, especially in poor rural areas, markets are often thin (with low volume of trade or a low number of transactions) or fail completely due to the high costs and risks of participation. However, avoiding markets is not a realistic solution for most small-scale producers, particularly those who seek commercial income gains from their investments into aquaculture ponds. With small-scale producers facing many general challenges (including limited land and capital, dispersed locations, limited transport and communications infrastructure, poor health and social and political marginalization), markets have the potential to help them overcome these challenges by providing income, generating employment, reducing poverty, empowering small-scale producers, fostering self-reliance and promoting pro-poor economic growth through enabling consumption linkages resulting in multiplier effects on growth (Penrose-Buckley, 2007).

Despite these challenges, the aquaculture sector is growing; small-scale aquaculture remains highly innovative and contributes significantly to global aquaculture production, although increasingly less so for many export products.

There are many opportunities to improve management and governance, thus increasing social and economic benefits to small-scale farmers. One such opportunity lies in promoting collective action among small-scale producers to create efficiencies of scale, orient investment and support empowerment of farmers through self-help groups, clusters or societies.

Supporting small-scale aquaculture

Better management practices

Low-yielding and unproductive small-scale aquaculture provides opportunities for improvements, although in some cases, opportunities or indeed the need for improvements may not be applicable, depending on household and other circumstances. Recent experiences show that application of better management practices (BMPs) through the establishment of farm clusters and farmer societies is effective in improving aquaculture governance and management in the small-scale farming sector. This approach enables farmers to work together, improve production and develop sufficient economies of scale and knowledge to participate in modern market chains and to reduce vulnerability. Such governance and management approaches improve the economic performance of the sector and strengthen producers' ability to participate in decision-making and self-regulation. Once such approaches are established and strengthened, a competitive and sustainable small-scale farming sector will become a reality.

Farmer organizations and lessons learned

Despite the market access and financial viability challenges, the aquaculture sector is growing, and small-scale aquaculture in Asia remains highly innovative and makes a significant contribution to global aquaculture production. An important opportunity to improve the governance and management of the aquaculture sector and thus increase the social and economic benefits to small-scale farmers might lie in promoting and developing collective action among small-scale producers in the form of producer organizations, cooperatives or other collective arrangements. Farmer cooperatives in agriculture have been universal mechanisms to facilitate the access of agricultural smallholders to better markets, although with mixed results in some countries.

There is little documented information on collective farming by more commercially oriented small-scale aquaculture producers and related aquaculture institutional arrangements. Nonetheless, the lessons learnt from recent experiences in the field show that promotion of cluster farming in aquaculture and managing these clusters using appropriate BMPs can improve aquaculture governance and management in the small-scale farming sector, enabling farmers to work together, improve production and develop sufficient economies of scale and knowledge to participate in modern market chains and reduce vulnerability (Boxes 1 and 2). This governance and management approach is a way of

improving the economic performance of the aquaculture sector and increasing producers' ability to participate in decision-making and self-regulation.

BOX 1. Farmer societies and the National Centre for Sustainable Aquaculture, India

In 2000, the Network of Aquaculture Centres in Asia-Pacific (NACA) began cooperating with the Marine Products Export Development Authority (MPEDA) of India's Ministry of Commerce, providing them with technical assistance for a "Shrimp disease control and coastal management" project focusing on giant tiger shrimp (*Penaeus monodon*), to address increasing anxiety over disease and the sustainability of the shrimp sector. The MPEDA-NACA project team developed better management practices (BMPs) to address the key disease risk factors along with food safety and environmental risks. The BMPs included recommendations for good pond preparation, high-quality seed selection, water quality management, feed management, health monitoring, pond bottom monitoring, disease management, emergency harvest, food safety and environmental awareness. The BMPs were disseminated through farmer meetings, regular pond visits, training of extension workers and the publication of ten brochures on BMP adoption, along with booklets on shrimp health management and extension.

Farmers were organized into self-help groups, originally called "aqua clubs" and now legally registered as farmer societies, which have joined to form "clusters" (groups of interdependent shrimp ponds situated in a specified geographical locality, typically comprising farmers who share resources or infrastructure such as water sources). The cluster concept was found to be a practical and effective way to improve management, provide risk management measures to farmers and thereby maximize returns. Thus, the organization of farmers into groups and clusters was used to facilitate the effective dissemination of BMPs among group members and also to enable them to more easily address the social and financial risks associated with small-scale shrimp farming and increase their access to input and output markets and services.

To continue the project, a separate semi-autonomous governmental agency called the National Centre for Sustainable Aquaculture (NaCSA) was created in 2007, with the approval of the Government of India. NaCSA not only facilitates the formation of farmer societies but builds their capacity and supports their activities to maximize their chances of success in achieving sustainable and profitable shrimp farming. The project has made significant progress, with the number of farmers adopting the cluster management approach growing exponentially from five farmers in 2002 (covering 7 ha in one state) to over 11 000 farmers in 2011. The production of BMP shrimp through the project has increased from 4 tonnes in 2001 to 4 160 tonnes for the first crop of 2009.

The NaCSA model has often been described as a success story of collective action and cluster management for sustainable small-scale aquaculture development. This is understandable given the numerous achievements of the project, including reduced disease incidence; increased productivity and quality; increased access to good-quality inputs; increased profit through reduced production costs; improved market access through increased ability to meet market requirements such as organic certification, traceability and eco-friendly sustainable production; and through linking societies to processors and retailers, revival of abandoned ponds, increased food security and sustainable livelihoods, and empowering small-scale farmers by giving them a "voice".

Source: Kassam, Subasinghe and Phillips (2011).

BOX 2. The Samroi-yod Shrimp Farmers Cooperative, Thailand

The Samroi-yod Shrimp Farmers Cooperative, located in Prachuap Khiri Khan Province in Thailand, was established in 2006 by shrimp farmers to help them respond to the decreasing international price of shrimp by increasing productivity through group-regulated production, provision of financial support, and enabling farmers to access sustainable output markets offering higher and more stable prices. The cooperative has been supported by the Network of Aquaculture Centres in Asia-Pacific (NACA) since 2008.

Cooperative membership currently stands at 158 members (115 men and 43 women). Members are mostly small-scale farmers with one or two ponds. Conditions of membership include farm registration, a minimum purchase of 200 cooperative shares and a small administration fee. Regardless of how many shares or how many ponds a member has, each member is only allowed to access cooperative services for one pond. Members also have to agree to follow the cooperative's regulations, established by the Executive Committee in order to increase the productivity and quality of shrimp, which is maximized when all group members follow the regulations. The regulations, which are similar to better management practices (BMPs) promoted by the National Centre for Sustainable Aquaculture (NaCSA) in India and by NACA elsewhere in the region, include maximum stocking densities and prohibited use of banned chemicals and certain antibiotics. The cooperative provides members with a number of important services, including credit for farm inputs, provision of technical advice, a computerized traceability system, increased market access through developing links with processors and buyers, and improved quality and safety of shrimp (through an internal control system).

A major achievement for the cooperative is increased market access due to its collaboration with a local processing plant and a European Union (EU) buyer. This partnership between the cooperative, processor and buyer is under consideration for Fairtrade certification and, if successful, will mean the cooperative will be producing the first-ever Fairtrade certified shrimp product. The cooperative has also increased members' access to good-quality inputs through negotiation of various partnerships and agreements with input suppliers and has improved the production and income of members.

Source: Kassam, Subasinghe and Phillips (2011).

Aquaculture farmer producer organizations or collective arrangements may have an important role to play in the sustainable development of the small-scale aquaculture sector through such actions as:

- enhancing participation and consultation of all stakeholders in the planning, development and management of aquaculture, including the promotion of codes of practice and BMPs;
- facilitating mechanisms for voluntary self-regulation for attaining best practices such as the cluster management concept;
- promoting the appropriate and efficient use of resources, including water, sites, seed, stock, finance and other inputs;
- developing human resource capacity by facilitating the provision of training, technology transfer and access to information;
- increasing market access through enhanced ability to meet market requirements, increased negotiation and bargaining power and economies of scale;

- facilitating the provision of extension services, credit and market information;
- developing government communication and consultation processes and promoting comprehensive policies and a supportive legal and institutional framework that support sustainable aquaculture development; and
- building partnerships with government to progress and implement policies and programmes, making government efforts and the use of scarce resources more cost-effective (Hough and Bueno, 2003).

An increasing number of programmes and projects are designed to explore and expand this successful “bottom-up approach” of empowering small-scale producers through farmer organizations. An example of such a project planned for implementation to support the small-scale farmers in Bangladesh is presented in Box 3.

BOX 3. Supporting small-scale farmers in Bangladesh

Building on lessons learnt from India, Indonesia and Thailand, a new project is being initiated to help facilitate the transfer of relevant experiences to Bangladesh. This project, funded by the European Union’s (EU) Standard Trade Development Facility (STDF), will empower 800 small-scale farmers to organize into manageable clusters and to develop and implement better management practices (BMPs), thus reducing the risks of antimicrobial contamination in shrimp and prawn products, and empowering them to better export. This will subsequently develop effective “bottom of the pyramid” solutions for compliance with the World Trade Organization’s agreement on the Application of Sanitary and Phytosanitary Measures (WTO SPS agreement) and related Codex Alimentarius and World Organisation for Animal Health (OIE) standards. As an end result, the concept of BMPs and cluster management to accomplish responsible and sustainable farming will be further strengthened, risks to food safety will be significantly reduced and small-scale farmers will secure better markets, thus improving their social welfare. The project, which is implemented by the Food and Agriculture Organization of the United Nations (FAO), is executed by the Department of Fisheries (DOF) in Bangladesh in close collaboration with the WorldFish Centre (WFC). Relevant industry organizations, including the Bangladesh Shrimp and Fish Foundation (BSFF), partner the project.

Source: Rohana Subasinghe, FAO.

What needs to be done?

An enabling environment including favourable business development policies, macroeconomic performance and legislation can have a strong influence on the success of a farmer organization. If government policies are not conducive to growth, there may be little point in investing resources in farmer organizations that focus on marketing interventions, which may provide some cushioning from the effects of bad policies but do not address the fundamental need for policy reform. Burnett and Greenhalgh (2002) make a number of suggestions on the kind of policy measures that can improve the functioning of markets to the

benefit of small-scale farmers and, in turn, farmer organizations highlighted in Kindness and Gordon (2001) as follows:

- Policies need to be adopted in industrialized countries that do not distort smallholder competitiveness in developing countries.
- Developing-country governments should be encouraged to adopt macroeconomic policies, particularly monetary and fiscal policies, that do not distort economic activities.
- Trade policy needs to be considered within a wider development context; better governance and reforms are needed to attract investment and trade opportunities.

Other issues related specifically to state support of small-scale aquaculture farmers that need to be addressed include the development of policy that is more favourable to the small-scale sector based on the requirements and realities of the small-scale aquaculture farmer; policies and incentives that encourage private investment in small-scale aquaculture production and services; provision of technical and marketing services that are more oriented towards small-scale aquaculture producers, as well as the small-scale traders and businesses associated with the sector; provision of social safety nets for the most vulnerable producers and traders; facilitation of access to financial and insurance services in rural aquaculture farming areas; and the provision of information services that cater to the needs of rural farmers (Kassam, *et al.*, 2011).

Aside from policies that constrain growth and do not address the needs of small-scale producers, in many countries, legal and regulatory frameworks can also constrain the operation and development of farmer organizations themselves through complicated administrative and bureaucratic procedures. Farmer organizations often lack the support and recognition of the state and are discriminated against and excluded. Simplifying administrative procedures and allowing easy, affordable and rapid registration and decentralizing administrative and legal procedures to regional or local levels are some of the ways in which governments can develop an institutional environment that is favourable to the free and effective functioning of farmer organizations. Governments should also accept the full operational autonomy and private nature of farmer organizations and recognize their positive contributions to rural and national development (SARD, 2007).

Inadequate infrastructure and transport can also be important constraints to the agricultural marketing activities of farmer organizations and small-scale farmers generally, particularly in remote rural areas. Even though this may not be part of the institutional environment, these issues fall under the wider enabling environment and must also be addressed by government if farmer organizations are to be able to achieve their objectives and be successful.

Conclusions

In summary, having established appropriate policy and legal frameworks to provide an enabling business environment, further efforts should be placed to build the capacity of small-scale farmers and their organizations. This might provide opportunities to build more equitable relationships with business, to minimize risks faced on both sides of the transactions, create synergies, and build confidence and trust between partners, and thereby promote a business model that would be sustainable and equipped to face the challenges of globalization.

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Alleviating poverty through aquaculture: progress, opportunities and improvements

Expert Panel Review 6.2

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Abstract

Significant changes in our understanding of the interrelationships between aquaculture and poverty have occurred in the last decade. In particular, there is a growing realization that the impacts of aquaculture need to be assessed from a

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value-chain perspective rather than through a narrow production focus. In recent years, understandings of poverty and the forms, outcomes and importance of aquaculture have also shifted. Terms in current use are first clarified, including those related to scale and location of aquaculture. The evolution of aquaculture from traditional to modern forms and its role as a central feature or more secondary part of household livelihoods are considered. Definitions of poverty and resilience and the potential roles of aquaculture in supporting poorer people are discussed in the light of recent research. The role and impacts of targeted interventions to support poverty alleviation are discussed and the potential negative impacts of aquaculture on poor peoples' livelihoods are presented. The concept of "well-being" is presented to support interpretation of the potential impacts of aquaculture on food and nutritional security. Strategies to ensure self sufficiency of aquatic foods at the household, community, national and international scale are considered. Access and food security issues affecting aquaculture and capture fisheries and the nature of farming are critiqued in the light of a broader literature. The role of ponds in meeting broader nutritional security needs and within rural livelihoods is discussed and the importance of incorporation into both local and more extended value chains examined. Since its take off as a major food-producing activity in the last few decades, aquaculture in many places remains a family business. Private governance through certification has emerged as a potential game changer in aquaculture, bringing with it the potential for exclusion of poorer producers from global value chains and associated implications for poverty alleviation. A distinction between the dynamic changes accompanying quasi-commercial and commercial aquaculture development, often in transforming economies, is contrasted with the incremental benefits associated with "quasi-peasant" aquaculture previously most associated with poverty alleviation through interventions supported by national and international organizations. A rethink regarding how poverty is most effectively reduced or its alleviation supported through aquaculture by supporting actors within value chains rather than with a sole-producer focus is advanced. An agenda allied to that proposed in the World Development Report 2008 (World Bank, 2007) for agriculture generally is proposed. This assesses the importance of aquaculture development as part of the measures to mitigate water scarcity and to support sustainable intensification of food production generally, while acknowledging the need to strengthen rural-urban linkages and continue the development of appropriate safety nets for the poorest groups.

KEY WORDS: *Aquaculture, Poverty alleviation.*

Background

Major changes in perspective have occurred since the Bangkok Declaration on Aquaculture ten years ago. These include: changes in the forms and outcomes of the activity and the profile and importance of the sector; thinking regarding the impacts on food security and broader development of the varied forms of

aquaculture that have evolved and; understandings of the nature of poverty and its alleviation. In the same year, the United Nations (UN) initiated and agreed upon eight Millennium Development Goals (MDGs) to guide development efforts and focus efforts towards significant poverty reduction by 2015. The present overview sets out to assess progress since Bangkok 2000, informed by both a wealth of new evidence from the field of aquaculture and a review of experience from the broader fields of agriculture, development and the environment.

The conventional view of aquaculture development based on the promise of “teaching a man to raise a fish” is still current (e.g. “Teach a woman to fish”, www.teachawomantofish.com/), but the very understanding of what constitutes aquaculture and how it should be developed, and poverty and its opposite, well-being, have undergone significant evolution in the last decade. Approaches to reducing poverty and their implications for aquaculture development, or aquaculture for development are considered based on recent research.

The broader development changes at policy level and how they have affected development thinking on poverty alleviation are first outlined before revisiting current views on the nature of aquaculture and how these have changed in the wake of accelerated globalization. The nature of poverty, vulnerability and well-being and evidence for links with aquaculture are then considered, followed by impacts on food security. Progress, opportunities and an assessment of the drivers required to enhance the poverty impacts of aquaculture are discussed in a final section.

Development

At the turn of the millennium, there was a “malaise” that beset support for rural development (Ashley and Maxwell, 2001), particularly regarding agriculture, for which support had fallen to 4 percent of official development assistance, despite 75 percent of the global poor living in rural areas (World Bank, 2007). A number of milestones have seen this situation change: the recognition that there were deep structural changes occurring within global agriculture, particularly regarding steep increases in demand for more animal-product rich diets in China and India; competition for food crops to support this demand; and biofuels. The first World Development Report (WDR) with a specific agricultural focus since 1989, criticized the World Bank’s past record on rural development (World Bank, 2007).

TABLE 1
Agriculture and poverty

Countries	Descriptors	
	Contribution of agriculture to growth (%)	Rural poor as a proportion of total poor (%)
Agricultural	>20	>50
Transforming	<25	>60
Urban	<20	<60

Source: modified from World Bank (2007).

It also identified three broad categories of country (Table 1) based on the contribution of agriculture to growth and the ratio of rural poverty to total poverty. Most of the countries in which aquaculture has been promoted to reduce poverty are transforming countries for which there are common structural characteristics, as well as a good deal of diversity (Table 2; World Bank, 2007). A pertinent paradox is that there are more poor people in countries considered medium income (MICs) than in the remaining 39 low income states (LICs) (Summer, 2010). A large proportion of this so-called “bottom billion” (Collier, 2007) live in countries where aquaculture is already important and expanding. The WDR agenda concerns seven broad recommendations for agriculture and poverty to which we return in the final section of this report.

Towards the end of the 1990s and the post-Asian financial crisis, a Post Washington Consensus (PWC) emerged around the need for a better balance between the neo-liberal and alternative views on development. The rise of neo-liberalism, i.e. a market-driven approach to development emphasizing the role of private enterprise, liberalized trade and a reduced role for the state,

TABLE 2
Structural features of transforming countries

Structural feature	Characteristics
Demographic pressures and declining farm size	The average farm size in Asia is already quite small – in Bangladesh, China and the delta areas of Viet Nam, it is a mere 0.4 to 0.5 ha. That decline will continue in South Asia because the rural population is growing at 1.5 percent a year and is not expected to peak until at least 2020. Continued population growth, declining farm size and growing landlessness put huge pressures on rural jobs.
Water scarcity	Freshwater supplies are already fully used in many countries, and escalating demands for industrial, urban and environmental uses will reduce the water available to agriculture. Water scarcity is particularly acute and projected to worsen with climate change and rising demand in the Middle East, North Africa and large parts of China and India. High reliance on groundwater irrigation in many countries has led to over-pumping, falling groundwater tables in aquifers with low recharge and deteriorating groundwater quality.
Lagging areas	Some rural areas have prospered with overall economic growth, but others have stagnated with high levels of poverty. Lagging areas are found in most countries in sub-Saharan Africa, the interior of China, several states in eastern and central India, the upland areas of Viet Nam and the drier areas of North Africa. The causes are varied – poor agricultural potential, low investment in roads and irrigation, poor governance, and social and ethnic marginalization. But some of those areas have good potential for agricultural growth and could be future breadbaskets, as in eastern India.
Political economy of agricultural policies	The political pressure of farmers to reduce the urban-rural income gap through protection and subsidies is increasing. Because of the large number of poor people, protecting food prices to raise farm incomes may have high costs for poor consumers, including most small farmers, who are net food buyers. Another form of support to farm incomes is through subsidies on inputs such as water and fertilizer. Those subsidies are not only regressive in distributing benefits to larger farmers and harmful to the environment but also distort fiscal priorities away from investment in core public goods, such as rural infrastructure. Political capture of protection and subsidies by larger farmers can slow the reform process.

Source: modified from World Bank (2007).

had previously divided opinions (Ashley and Maxwell, 2001; Onis and Senses, 2005). Since that time, dialogue between these polar opposites has continued and fresh thinking on bridging the gap has emerged (Dorward, 2009). Ashley and Maxwell (2001) identified several of the elements of the PWC including agriculture remaining an engine of rural development, the future viability of small farms, the potential of the non-farm economy and impacts of new thinking on poverty, governance and participation which are pertinent to framing ideas about support for aquaculture and its role in rural development and poverty alleviation.

The World Development Report (2001) recognized the multidimensional aspects of poverty, and since then there have been new avenues of thinking that articulate the links between poverty and the environment, particularly the concept of social and environmental resilience (Folke *et al.*, 2002). The WDR 2008 (World Bank, 2007) focus on agriculture was timely, as the global food shock occurred in the same year, galvanizing renewed interest in the sector and, as acceptance that climate change was a reality, a need for structural transformations of political and social institutions to meet expected challenges in the coming decades. Another milestone in the last decade has been acknowledgement of the central role of the private sector in aquaculture development (private sector development, PSD), set out in the World Bank's *Aquaculture: Changing the Face of the Waters: Meeting the Promise and Challenge of Sustainable Aquaculture* (World Bank, 2006).

Defining aquaculture systems

A range of terms is in common usage to define and describe aquaculture systems and those who operate them. In principle, definition should reflect clarity of purpose and thereby interpretation of impact. Does investment in “small-scale” aquaculture necessarily result in more poverty reduction than in “larger-scale” aquaculture? Do classifications based on simple physical scale indicators allow comparisons between species and across locations or between alternative property rights (formal and informal), for example? The various classifications in current use are explained and compared in the context of evaluating their values for understanding the relationship with poverty.

Classifications

Aquaculture systems have been defined in terms of location (e.g. inland/coastal, lowland/upland, rural/urban), salinity (i.e. freshwater, brackishwater, seawater) and level of intensification (i.e. extensive, semi-intensive and intensive). They have also been characterized by the form of containment (e.g. rice field, pond, cage, tank/raceway) and the trophic level of the species cultured (e.g. autotrophs, herbivores, omnivores, carnivores). In terms of impacts on people, definitions that embrace aspects of consumption (e.g. subsistence compared to commercial orientation) have been commonly used, often in tandem with consideration of market (i.e. “local”, urban, regional or international).

All of these classification systems have connections to the issue of impacts on poverty alleviation. Some forms of aquaculture undoubtedly require investment beyond the reach of poorer people: raising carnivorous species using nutritionally complete feeds in intensive systems might be expected to be less poverty focused than producing herbivorous species in rice fields. Furthermore, poverty may be spatially concentrated in rural or urban contexts or be more extreme and/or widespread among certain ethnic communities. Promoters of aquaculture in upland or mountainous areas of Viet Nam for example have used the poorer, more marginalized nature of resident populations as a rationale for securing funding.¹

Scale as a descriptor

Scale of production, with definitions typically based on indicators of area, numbers of culture units and levels of inputs and/or outputs, has been a common identifier of aquaculture systems and habitually linked with its role in poverty alleviation. In particular, “small-scale” aquaculture and “poverty alleviation” have become almost synonymous. The usefulness of such definitions has recently been challenged (Edwards, in press^a), as has the usefulness of relating scale to policy (Tripp, 2001) or poverty alleviation at all (Belton, Haque and Little., in press). Defining both small-scale fisheries and farming (Ashley and Maxwell, 2001 and Grigg, 1966, respectively) have also been problematic. Differentiating between scale on the basis of size of holding, dominance of aquaculture within the livelihood, or status as owner, lessee, operator, employee or subcontractee of the enterprise reveals inconsistencies.

A recent Food and Agriculture Organization of the United Nations (FAO) workshop (Bondad-Reantaso and Prein, 2010) defined small-scale aquaculture as a continuum across a fairly broad range of characteristics. For example, in the Viet Nam *Pangasius* industry the “medium-size” farmers involved tend to have the critical mass of capital which allows them to create the economies of scale large enough to maintain access to global value chains (Bush and Duijf, 2011). This contrasts markedly with shrimp in Viet Nam, where production systems are large in terms of area but have relatively small outputs (Thanh *et al*, *unpubl. data*). However, the macro-data suggest that *Pangasius* and shrimp farmers are similar in that their main livelihood activity is aquaculture, largely because their land has been converted to ponds, or they have very little alternative given the location of their land in often marginal and/or coastal ecosystems. Some studies have indicated that *Pangasius* systems are more heterogenous than recent publications might suggest (Labrousse, 2008) and point to a basic issue that undermines understanding of the diverse forms of aquaculture: sampling frameworks are often either *ad hoc* or absent, leading to generalizations based on what are essentially case studies.

¹ An example is the presentation by N.T. Tung on *Aquaculture and poverty reduction: experiences of UNDP Vietnam* given at the EC Workshop on Sustainable Rural Development in the Southeast Asian Mountainous Region, Hanoi, 28–30 November 2000.

TABLE 3
Typology of the social and material characteristics of pond-based finfish culture

Relations of production	Characteristics					
	Quasi-peasant		Quasi-capitalist		Capitalist	
Production intensity	Low	Low or moderate	Moderate	Moderate or intensive	Moderate or intensive	Highly intensive
Capital & operating costs	Limited	Moderate	Substantial	Substantial	High	Very high
Ownership & labour	Family owned & operated	Family owned & operated	Family owned & operated	Family owned & operated or absentee owner Part-time &/ or permanent labour	Family owned & operated or absentee owner Permanent labour Managerial staff	Absentee owner or corporate ownership Permanent labour Professionalized managerial, technical & clerical staff
Organization of production	Minor activity in a portfolio of livelihood options	One of a portfolio of livelihood options	Primary livelihood activity	Primary livelihood activity or entrepreneurial investment activity	Primary livelihood activity or entrepreneurial investment activity Possible or partial or complete vertical integration	Entrepreneurial investment activity or large business Likely partial or complete vertical integration
Market orientation	Subsistence/local/district		District/urban/national		National/export	

Source: from Belton et al, in press.

More recent research suggests that a focus on scale can be misleading, and a “relations of production” approach has been advocated to better understand the various impacts of aquaculture on poverty (Belton, Haque and Little, in press; Belton and Little, 2011a). These authors proposed that the use of scale be abandoned and aquaculture be categorized in terms of relationships (e.g. “quasi-peasant”, quasi-capitalist and capitalist) to overcome some of the inherent problems relating scale to production intensity, capital and operating costs, ownership and labour, and organization of production (Table 3).

Undoubtedly these redefinitions that have been developed primarily for pond-based aquaculture are closely aligned with previous definitions that differentiate between subsistence and commercial orientation or “small-scale” and “large-scale” aquaculture (see below). But the new terms, based on a Marxist analysis as applied by sociologists, are a significant improvement for understanding aquaculture development across a broad landscape, both geographically and socially. Using labour as the unit of interpretation, it allows a better analysis of motivations and outcomes and a closer articulation of where aquaculture

“fits” in complex livelihoods. Its application allows the fast-changing realities in the sector in countries both termed “agricultural” and “transformational” and a better framework to assess the links between aquaculture and poverty alleviation that extend beyond the pond, outside the farm and along the value chain.

Definition by location: rural vs urban

Rural aquaculture derives from the attempt to differentiate between “rural and agricultural” and “urban and industrial” (Edwards, in press^a). Martinez-Espinosa’s binary classification of rural aquaculture that separated Type 1 (poor, subsistence oriented) from Type 2 (less poor, commercially oriented) in 1995 set the scene for its reinterpretation, but this has been beset with problems of definition and boundary setting. Definitions of “rural” (see Edwards, in press^a) as synonymous with small-scale farming and poverty (Edwards, Little and Demaine, 2002) have also remained largely uninformed by the growing literature on rural-urban linkages and the complexity that this adds to the issues of addressing poverty in specific locations. Increasing interpenetration of rural and urban livelihoods makes urban and rural poverty interconnected (Rigg, 2003). For example, in the rural context of Thailand, few “farmers” are totally reliant on agriculture and increasingly base their livelihoods on non-farm income; people in rural areas are becoming “land short, farming shy and consumption inclined” (Rigg and Natapoolwat, 2001). Moreover, trajectories of rural change that influence attitudes and practice penetrate across borders into hitherto “remote” rural areas (Wiggins and Proctor, 2004); Bouahom, Douangsavanh and Rigg (2004) describe such changes in agriculturally marginal areas of Lao PDR.

In the case of some peri-urban aquaculture, this works both ways. The production of water spinach (*Ipomoea aquatica*) is commonplace around urban centers in Asia, and this aquatic vegetable tends to be produced by people poorer than those who produce finfish, which requires more resources. Access to shallow converted rice fields or common-pool resources such as urban waterways and lakes is the main requirement. In Boeung Cheng Ek, a large waterbody that receives and treats most of the sewage in Phnom Penh, Cambodia, poor communities are actively engaged in producing and trading the vegetable that makes up an estimated 50 percent of the green vegetables consumed in the city. Many of these people are migrants from rural provinces, and the population rises and falls with the labour requirements for rice production in their home villages (Leschen, 2006).

Such types of urban-rural linkages complicate the challenge to define any generic form of “rural” or “urban” aquaculture; recent characterizations of rural aquaculture include “to provide low-cost fish for poor rural and urban consumers” (Edwards 2000, in press^b). Certainly, much of the growth in aquaculture in recent decades has been stimulated by urban demand and supported by urban-based services, whether government, non-governmental organization

(NGO) or commercial (Little and Bunting, 2005). Drivers for the development of aquaculture are often related to urbanization to meet demand for food in towns and cities, and underpinned by reciprocal investment and inputs, both knowledge and physical requirements such as feed, seed and equipment. The implications for poverty impacts are important, as urbanization itself is changing the very nature of poverty (see below). One approach is to accept that terms such as “rural” and “small-scale” are only useful in respect to specific contexts; another approach is to provide more location and context-specific definitions.

Edwards and Demaine (1997) originally linked the term rural aquaculture to “rural development” but more recently, Demaine (2010) asserts “rural aquaculture should be retained for low-cost production systems suitable for implementation by the rural poor”. This definition is undoubtedly more precise and therefore potentially more valuable for targeting interventions and development assistance but could effectively exclude much of the aquaculture more recently appreciated to have impacts on poverty. Not only has there been accelerated development and uptake of higher-input aquaculture in many areas, but it is also clear that many, if not most, of the poor who benefit from aquaculture in rural areas are not producers (Hambrey, Edwards and Belton, 2008). Moreover, better-off rural producers may prefer “low-input” aquaculture, and poorer producers “higher input” aquaculture for a range of reasons. This may be linked to the fact that whereas aquaculture may constitute a very small part of better-off households’ overall portfolio of activities, it may be far more significant for the poor.

Edwards (in press ^a) also differentiates between “traditional” and “modern” aquaculture and identifies many of the inherent contradictions in assuming traditional aquaculture is always small-scale and poverty focused. The extensive holdings characteristic of traditional brackishwater aquaculture in Hawaii, Indonesia and the Philippines suggest otherwise (Wyban, 1992; Costa-Pierce, 2002). Clearly, the emerging diversity of “modern” systems has varying direct relationships with poverty alleviation.

From tradition to modernity

“Traditional” aquaculture was, until the hatchery revolution that began in the 1980s on a large scale in Asia, probably highly geographically limited to relatively better-off pond owners able to obtain naturally sourced juveniles. There is little evidence that it benefited the poor to any great extent, although it undoubtedly took place in poor rural societies (Beveridge and Little 2002, Edwards, in press^a). Rural people generally met their subsistence needs for fish through accessing natural stocks from resilient flood-plain, lacustrine and coastal resources. Such resources supported large numbers of full-time or part-time artisanal fishers in areas where these were abundant. Of the large diversity of “modern” systems that have evolved, many have evolved, sometimes incrementally, from “traditional” forms and remain integrated into local agricultural and broader livelihood systems. They are characterized by a dependence on seed and feed

from outside the farm and the immediate community and derived from specialist actors (i.e. hatcheries and feed processors, respectively).

Responding to increased demand for farmed fish and a decline in the relative abundance of natural stocks, “modern” systems can generate large networks of opportunity from which poorer people can benefit. A good deal of this employment is outside the production enterprise; use of purchased formulated feeds reduces the need for on-farm labour but can stimulate employment in the supply chain. Other types of “modern” aquaculture are introduced enterprises distinct from surrounding food production and may be fully integrated with global value chains from the outset. To fully assess these opportunities requires that boundaries be set further than the farm gate and, increasingly at distance from the site of production by considering the whole value chain and how poorer actors are affected as employees, service providers and consumers. This approach is also required to assess environmental impacts of aquaculture, given that recent life cycle assessments (Bosma, Hanh and Potting, 2009; Pelletier and Tyedmers, 2010) have suggested that the majority of the environmental impacts (e.g. embodied energy, global gas emissions) of such “modern” forms of aquaculture result from feed production and use. Pumping and aeration for intensive systems and postharvest processing and distribution can also be very important.

Evolving forms of aquaculture

Fresh perspectives are also required on what constitutes “aquaculture” in order to inform our understanding of its importance in alleviating poverty. While most observers agree that the household-level enterprise, whether relatively small or larger-scale, located in a more or less rural location, remains the dominant type of enterprise in contrast to “corporate” enterprise, the utilization of aquatic resources encompasses an increasing variety of forms of social organization. This is partly an outcome of the increase in demand for and pressure on access to water, particularly hitherto common-pool resources. These range enormously in size and management approach and offer both new opportunities and potential conflicts with poverty alleviation.

Knowledge of property rights is a key determinant of aquaculture potential in common-pool resources which necessitates some degree of collective action or agreement. Potential for free-riding, difficulties guaranteeing returns to individual effort and the associated difficulties in meeting transaction costs of management mean that such development efforts tend to be relatively extensive in nature. Requirements for external institutional mediation may increase with scale.

Security of access to smaller group “common property” systems or those with seasonal common-pool characteristics (e.g. flood plain areas of Bangladesh) is often complicated by dynamic systems of overlapping statutory and informal

property rights referred to as “legal pluralism” (Meinzen-Dick and Pradhan, 2002). Depending on resource context, this can result in greater uncertainty, i.e. due to imperfect knowledge, or greater flexibility resulting from interaction of the different rule-systems.

Cage and enclosure-based aquaculture located in common-pool resources and typically dominated by commercial interests effectively privatize the resource, and this can have implications for multiple use through access modifications and environmental impacts (Beveridge, 2004). Some forms of management have developed from traditional fishery models, e.g. fishing “lots” in the Tonle Sap (Lamberts, 2001) and the leasing of perennial waterbodies in the Indian subcontinent that have been revenue generating and extraction oriented. Stocking hatchery seed in such culture-based or enhanced fisheries has now become a major type of development initiative and often cloaked in “participatory” and pro-poor approaches. Increasingly, smaller waterbodies, “community” ponds or rainfed irrigation tanks or areas of inundated floodplain enclosed by bunding are being leased for stocking and management to individuals or groups (Gregory, Brooks and Toufique, 2006; Valbo-Jørgensen and Thompson, 2007). These types of aquaculture raise issues concerning the continued traditional rights of the poor for access and exploitation of wild stocks (Nguyen Khoa *et al.*, 2005). This parallel trend towards more extensive forms of aquaculture, often based around managing both stocked and unstocked species, points towards alternatives to intensive monoculture as approaches to increase aquatic food production. As for agriculture more generally, the production of farmed and wild aquatic foods is often complementary (Beveridge and Little, 2002; Bharucha and Pretty 2010). The boundaries of the various practices considered to be aquaculture and capture fisheries are therefore becoming blurred, and previous truisms that aquaculture is “for” the resource rich and fishers are the “marginalized poor” are open to debate. A study that identified and characterized household-managed aquatic systems in five countries in Asia found that farmers generally regarded stocked and unstocked animals, especially in less intensive systems, as complementary and more capable of meeting their diverse household needs (Morales, 2007). Up to 90 percent of rice farmers in Cambodia and northeast Thailand harvested aquatic animals, and 70 percent created aquatic habitats such as ponds, principally to reduce seasonality and enhance catch per unit effort (Amihat *et al.*, 2009a, b).

Aquaculture as a component of livelihoods

An appreciation that aquaculture may be one part of a complex livelihood portfolio (Scoones, 1998) rather than being the sole or main income-producing focus for a household also changes the way in which it can be perceived and defined. This also has implications for its relationship with poverty alleviation. Involvement in aquaculture value chains may be seasonal, part-time, or both and this may have very different consequences for household poverty than a complete dependence on the activity. Furthermore, many types of aquaculture are, and always have

been, too small or unproductive to support livelihoods entirely or to make large contributions to them. The planned or primary roles of many on-farm ponds were typically multipurpose; water storage for supplementary irrigation and domestic needs and trap ponds for wild fish were commonly cited as the original intention in a study of three countries (Little *et al.*, 2007^a). This study suggested a shift towards aquaculture becoming a relatively more important use for such ponds, although the importance varied considerably; the crucial aspect remained that ponds were viewed as assets integrated within diversified livelihoods (see also Dey *et al.*, 2010).

Focusing on the pond leads to a more asset-based understanding of aquaculture. For both small-scale rural aquaculture (the type addressed by Edwards, Little and Demaine, 2002) and globally integrated production systems, the pond remains the central asset. The integrated farming systems literature certainly places the pond at the center of household livelihoods, usually as a managed sink and source of nutrients used to improve low-cost growth of fish, livestock and cash crops (Edwards, Little and Yakupitiyage, 1997; Nhan *et al.*, 2007). An alternative “integrated” understanding of ponds in inland floodplain areas of Southeast Asia is as a dry season water source and/or as monsoonal trap pond systems (Demaine *et al.* 1999; Shoemaker, Baird and Baird, 2001; Dey *et al.*, 2010). Ponds in these farming systems have a central role in rural livelihoods; as such, once a pond is dug it may well change use but is rarely if ever abandoned.

The promotion of aquaculture separate from, or integrated within, broader livelihoods therefore becomes an important policy issue. In the last decade, aquaculture has in some cases been embedded within national poverty reduction strategy plans or has become a key part of macro-economic growth or, in some cases (e.g. Viet Nam), both. The renewed interest in the ways in which various types of aquaculture can contribute to poverty alleviation at household, community and national levels is critical.

Current theory and concepts related to poverty and its alleviation

Introduction

A general assessment of current knowledge regarding poverty alleviation is presented with an outline of some of the current thinking about poverty, well-being and life satisfaction among development and related sectors. The key approaches to describe and assess poverty from economic (particularly income and expenditure) approaches through to broader analysis of assets, to more holistic well-being approaches that consider how poverty is experienced are described. The assessment of these multiple natures of poverty also considers the relationship with vulnerability and resilience, as well as intergenerational poverty, its causes and characteristics of approaches to alleviate it. One aspect of the dynamics of poverty is that in any given context some households are

falling into poverty while others are escaping from it, and this is considered in terms of the potential roles of aquaculture. The impacts of aquaculture on equity are also considered, given recent illustrations of the rapid increases in wealth and wealth differentials that are possible in communities and issues related to power relations constraining benefits to the very poor.

The multiple nature of poverty has made it a challenge to link its reduction or mitigation directly to development initiatives, both informal and formal, in any sector. Stevenson and Irz (2009) made the point that “ideally the impact of aquaculture development on the poor would be investigated by measuring robust poverty indicators to allow comparison of the existing situation with a counterfactual (i.e. situation without aquaculture) built from convincing data to establish causality/attribution”. Aquaculture development has been advocated for its potential benefits for the poor and linked, sometimes implicitly, to development of this specific group, although it has tended to have a strong technocentric focus and favour the better off (Edwards, 2000). The opportunities for aquaculture to benefit the poor, given its often resource-intensive nature, have been challenged (Harrison *et al.*, 1994; Lewis, 1997) and indeed implicated in the development of greater inequalities (Adger, 1999; Van Mulekom *et al.*, 2006).

Since the 1950s, there has been a focus on “small-holders” as producers as the main channel for poverty reduction in line with mainstream agriculture: the so-called “small-farmer-first narrative” (Ellis and Biggs, 2001). Although the earliest attempts to promote aquaculture throughout sub-Saharan Africa involved digging household ponds, an exact parallel in aquaculture is less clear in many countries in Asia, as historically pond owners have often been a relative elite in rural communities; and furthermore, many forms of aquaculture are resource intensive. This has always been context specific, for example, where anyone relatively poor is virtually landless, such as in Bangladesh, as opposed to areas where even the poorest people have significant landholdings. This view also ignores the spread of pond construction among even poor households as the real cost of excavation and earthworks has declined, often in tandem with the expansion of road networks across much of Asia. It also reflects too narrow a view of the range of aquatic resource management now embraced by the term aquaculture (see above).

Critical questions on the characteristics of the poor and their involvement in, or exclusion from, aquaculture (as producers, intermediaries, consumers) are considered below. A key issue is whether such involvement or exclusion reduces vulnerability, enhances security or, more dramatically as is often claimed, supports escape from poverty. The nature of poverty and how it can be assessed are considered and implications for the potential roles of aquaculture in its mitigation. Conceptual frameworks such as livelihoods, global value chain and resilience models are invoked. An issue for assessment of aquaculture

stakeholders is their absolute and relative levels of wealth or well-being: are they poor; and if so, assessed by what criteria? Are they poor in “absolute” terms or relatively poor compared to others in their communities? Critically, is involvement in aquaculture the most appropriate means to escape poverty? The causes of poverty may be related mainly to limited assets at a household or individual level or to broader institutional factors. In most situations, it will be a complex of these factors that results in the specific impoverished livelihood and asset accumulation of various types that is critical to escape from poverty. The specific mechanisms through which involvement in aquaculture as a stakeholder enhances various types of asset and reduces vulnerability are also explored in this section.

Definitions

The various definitions of poverty are first considered. Simplistic and all-embracing views of poverty such as use of financial indicators or USD1.25/day income are useful but disguise a much greater range of “conditions” ranging from absolute degrading poverty to the various types of poverty recognized, such as income, nutritional and cultural. The Millennium Development Goal (MDG) 1 is to halve poverty and hunger by 2015. It has five indicators that span the more orthodox measures used: the proportion of population living on less than USD1.25/day, the poverty gap ratio, the share of the poorest quintile in national income or consumption, the prevalence of children under five who are underweight and the proportion of the population that is malnourished.

The multifactorial nature of poverty is well recognized. The World Bank has developed multifactorial indices, a “descendant” of the United Nations Development Programme (UNDP) Human Development Index, for measuring and describing the complexities of poverty. An issue with such combined measures is the degree to which progress away from poverty in one aspect is correlated with the others. Gentilini and Webb (2008) found that describing a given country performance in attaining MDG1 using a poverty and hunger index (PHI) could describe a given country performance in attaining MDG1 in a single number, while at the same time showing that progress in one dimension such as income poverty did not automatically translate into improvements in others such as children underweight, and vice versa.

The term “trapped in poverty” is a reminder that although there has been much dynamism with regard to poverty, some is also chronic and intergenerational. Moving away from this state, either individually or collectively, can be constrained by a variety of factors including powerlessness, uncertainty and insecurity (Wood, 2003) and/or is related to poor physical and mental health.

The terms alleviation, mitigation and reduction are used interchangeably and when applied to aggregate levels of poverty can be synonymous. On an individual or household level, however, use of the first two terms suggests

that people remain poor but that the worst symptoms or outcomes of poverty are “relieved”, whereas poverty reduction suggests the underlying causes of poverty are addressed. It is also useful to differentiate poverty from vulnerability and insecurity. “Vulnerability” is not synonymous with poverty but means defencelessness, insecurity and exposure to risks, shocks and stress (Gordon and Spicker, 1992 in Hallman, Lewis and Bugum, 2003). The role of a resilience perspective for understanding the dynamics of social and ecological systems for effective change in governance has also been advocated (Duit *et al.*, 2010).

Uncertainty underpins the condition of poverty in many contexts and also prevents investment by individuals – the so-called “Faustian bargain” (Wood, 2003). Chronic, rather than random, or stochastic, insecurity is the major challenge to poor people. Longer term goals are put on hold. The idea that households and the individuals therein can “graduate” away from poverty and vulnerability in the face of a hostile environment, both social and environmental, is in many cases naïve unless pro-active support is given. In practice, the “extent of their capacity for social action” is a major constraint, and the poorest people are excluded. For example, poor fishers cannot make the time for, or through low social status are excluded from, decision making or participation in group resource management.

Aspects of vulnerability may be most intense at the intra-household level (Hallman, Lewis and Bugum, 2003), e.g. females’ dependence on males or subordination, lack of knowledge of production technologies or market opportunities. Ex-household factors such as law and order, threats of violence (e.g. to minority households at times of social tension), forced sales of land, takeover of waterbodies previously communally accessed (resource capture), theft of fish, malpractice by local hierarchies, low levels of trust in government/NGOs and lack of access to services are also clearly critical.

Various aspects of prevailing culture may intensify social norms; the distinction of “outside” and “inside” work in the Bangladesh context for women makes their roles in aquaculture highly dependent on its location. Barman and Little (2011) found this in piloting of fish nursing systems in northwestern Bangladesh – hapas in seasonal ditches within the homestead could involve women whereas “in the field” technologies effectively excluded all but the poorest, for whom such social rules were less constraining.

Differences in mechanisms through which aquaculture might impact on wealth and “well-being” are also considered below.

Poverty dynamics

A large number of studies indicate that many households fall into poverty, including non-borderline households, due to a combination of factors that typically include poor health of the major breadwinner. Using a “stages of

progress” methodology, Krishna (2007) showed that decline was typically gradual and cumulative – ill health and high healthcare costs were by far the most important reason for decline, adding to costs and reducing income-generating opportunities. Social/customary costs (e.g. dowry, funerals and weddings), high-interest debt, drought/flood and other land-related factors were also associated with descent. The extent to which, if at all, participation in aquaculture can protect households from decline or indeed exacerbate it (e.g. through taking loans for non-productive ponds) needs further study. In a comparative study of the role of self-recruiting species in aquaculture in Cambodia, Thailand and Viet Nam Morales (2007) found that loss of a household head and a relatively large number of dependents were major factors in households being viewed as poor within communities.

Aquaculture is also relatively new, and intergenerational impacts are far from clear, although some studies in Central America (Lovshin, Schwartz and Hatch, 2000) and Thailand (Belton and Little, 2008) suggest that these are occurring. Haque *et al.* (2010) found that primary adopters of fingerling production in ricefields were more likely to invest the income from fish sales in their children’s education than the secondary adopters, who tended to be slightly wealthier.

Aquaculture can contribute to producer household livelihoods in terms of improved nutritional and health outcomes, and transferable skills such as business and networking, i.e. enhanced human assets and productivity elsewhere on the farm, or the capacity to work more profitably off-farm.

Krishna’s multicountry study (2007) found that income diversification (either on or off-farm) was the most important pathway out of poverty, a finding also supported by a study carried out in Bangladesh (Sen, 2003). Private and public-sector employment was far less important, as was education or public or NGO assistance. Access to on or off-farm irrigation was important to over a quarter of households escaping poverty in the three parts of India assessed by Krishna. The extent of aquaculture’s potential to support escape from poverty in irrigated, high-potential contexts, as compared to more marginal rainfed environments where ponds provide on-farm water storage, is likely to be different and is considered later.

The perception that aquaculture is not an option for poorer households because of a requirement to access resources has already been challenged above, but the extent to which adoption of aquaculture has resulted in greater wealth, has also been under-assessed. Initiating aquaculture outside of the geographically highly restricted areas that had ready access to wild seed was historically limited by availability of hatchery-produced juveniles and knowledge of how to raise them. Adoption studies suggest that when demand was sufficient, even variable levels and quality of information and seed have been sufficient for pioneers to embrace the practice, typically followed by others after

demonstration of its potential (Surintaraseree and Little, 1998). The nature of rural extension networks has often resulted in those with closer relationships to such social resources accessing them first – typically these would be wealthier, more mobile and better educated individuals. Often they have high social status, with public-sector positions themselves or strong kinship links with those that do. Commonly, it can be observed that farmers who upgraded their position in the value chain, particularly from growing food fish to hatchery production, would possess these characteristics.

As with other development initiatives, the knowledge that promoting aquaculture among the relatively better off is both easier and potentially more cost effective has led donors aiming to focus on reduction of poverty through aquaculture to re-evaluate their approaches and introduce some form of targeting, and these are now considered.

Targeting poverty

Reasons for the dynamic nature of poverty (i.e. that at any particular time people are simultaneously both falling into poverty and escaping from it in large numbers) need to be understood and targeted, rather than just the people (Krishna, 2007). An improved understanding of the extent to which aquaculture can improve people's well-being while they remain poor, as compared to being part of a process that removes them from poverty (i.e. allows them to “escape”), is required.

Targeting of poverty relief programmes has used indicators: geographical, community and self-targeting; all have problems. It is not unusual for targeting to result in contradictory outcomes. The social and political networks of the better off may give them significant advantages to claiming benefits, potentially further undermining the situation of the needier. Mixed approaches are also common, such as when aquaculture has been promoted in a certain geographical context; areas where fish is perceived as being particularly important and/or lacking among ethnic minorities for whom aquatic foods are relatively more important than for mainstream communities would be an example of this (Barman, 2009). Community-based approaches may aim to support the poorest households wanting to access ponds (self-targeting). Examples of this are food-for-work programmes in which the poorest are attracted to daily waged employment constructing ponds. Depending on the programme structure and prevailing institutions, however, this does not necessarily result in any sustained access to the completed resource by those who have built it.

Elite capture is a regular criticism of development projects, even those in which participatory approaches at the “community” level are central to the approach (Plateau, 2004); aquaculture extension projects appear to be particularly vulnerable to such outcomes. Some studies have found that this problem is not insurmountable, especially where inclusion of both elites and non-elites in democratic self-governance was established (Das Gupta and Beard, 2007).

Targeting, through a focus on poorer individuals or groups rather than the broader community may also create or exacerbate social tensions and has been the rationale for not attempting to target within communities (e.g. the Northwest Fisheries Extension Project's village fishponds approach; Islam, 2002). Those at most risk of falling into poverty have rarely been targeted by specific poverty-reducing programmes, although they possibly have been the target for rural aquaculture promotion, i.e. farming households with small ponds. Recent analysis in Mymensingh District, Bangladesh, suggested that marginal farming households were quite likely to have ponds, but that poorer households were not (Belton, Haque and Little. *in press*). A similar conclusion was reached in Malawi (Dey *et al.*, 2010).

Targeting the poor to benefit through aquaculture may be more straight forward in contexts where a larger proportion of the rural poor have land, especially where ponds or small waterbodies of various types are a common asset and used to some extent for fish culture. In Central Luzon, Philippines, an Asian Development Bank (ADB) funded study found that almost 50 percent of farmers with ponds less than 1 000 m² were below the poverty line (ADB, 2004). In Sisaket, northeastern Thailand, ponds of poorer people more dependent on off-farm income were more likely to be abandoned or used as trap ponds and much less likely to be in active use (Turongruang, unpub. data). In the Red River Delta, ponds are a traditional component of the integrated homestead systems, for example, the vegetables, aquaculture and cage system (VAC) (Luu *et al.*, 2002). Morales (2007) found that both the well-being status of households and the specific agro-ecosystem (i.e. low-lying flood-prone areas compared to drier more upland sites) affected the likelihood of having a homestead pond. Better-off households in more upland sites were more likely to have a pond (>60 percent) whereas poorer households in flood-prone environments were least likely, but even in the latter group, more than 20 percent of poorer households had ponds.

Project interventions

The PWC on how rural poverty could be reduced is based on the premise that most poverty remains rural (Ashley and Maxwell 2001), but “rural” is a highly diverse and dynamic category. In less well-connected or remote rural areas with few resources, there are few proven strategies to reduce poverty through agriculture except outright subsidies (Wiggins and Proctor, 2004). Where rural areas are well endowed in terms of natural resources, agricultural development is possible and desirable; but reducing poverty may still require interventions to make markets work by correcting for failures and by strengthening institutions to that end (Dorward *et al.*, 2004); hence, the concept of the project-based intervention that promotes aquaculture in targeted areas and to targeted groups that otherwise would miss out on such opportunities. Typically, however, such projects have neglected institutional issues, at best recognizing their importance as part of an “exit strategy” rather than as core objectives. A major

issue is if project-oriented subsidized approaches to development have resulted in significant improvements in poverty alleviation, and if these have been cost effective compared with other forms of investment. Brummett, Lazard and Moehl (2008) described the failure of aquaculture development approaches in sub-Saharan Africa and urged a re-alignment towards support for small and medium enterprises (see also Beveridge *et al.*, 2010).

Claims regarding the linkage between poverty alleviation and aquaculture, particularly “small-scale” aquaculture, have intensified in recent decades in response to donor pressures and the “small-farm first” paradigm, despite the weak theoretical underpinning of the latter with respect to aquaculture (see Belton, 2010; Belton and Little, 2011a).

Strategies to benefit the poor through aquaculture – a commercial aquaculture focus?

A key reason for definitions is the issue of targeting – focusing development efforts in its various forms at those most in need and/or where the maximum impact can be achieved for a given level of resource.

The case that enhancing agricultural productivity as a whole is the most effective mechanism for reducing chronic poverty remains current and has recently been revisited by economists (e.g. Irz *et al.*, 2001). More commercially oriented aquaculture, rather than aquaculture geared primarily to meeting subsistence needs, appears to generate larger employment networks which offer more opportunities for poorer people to benefit than smaller-scale more subsistence-oriented systems (Hambrey, Edwards and Belton, 2008; Belton Haque and Little, in press). This view has recently been discussed among aquaculture professionals working in Africa, with similar overall conclusions (Leschen and Dabbadie, 2010) and both Brummett *et al.* (2008) and Beveridge *et al.* (2010) came to similar conclusions.

A study of commercial aquaculture in the Philippines produced strong evidence that aquaculture benefited both non-poor and poor but that the latter derived a relatively larger share of their income from it and that across a range of production systems that aquaculture tended to reduce inequality (Stevenson and Irz, 2009). The range of employment opportunities that commercial aquaculture stimulates, while showing high variability between different systems in the same location, appears to be the major benefit, particularly in areas with large surpluses of labour. It also attracts more highly qualified individuals into the sector who themselves leverage greater private-sector investment. A further series of studies in the same area in the Philippines identified that while the poorest members of communities in which aquaculture was located did not benefit through direct employment, indirect employment was “enriched” through the opportunities for informal gleaning of emptied ponds and associated fishing and trading (Parker, 2008). Gleaned by-products (e.g. shrimp) entered global value chains and supported local

subsistence of the gleaners themselves and even more impoverished community members through gifting and reciprocal exchange. A major concern was that these long-established systems, while showing resilience to environmental and population pressures, would be sensitive to further technological improvement that resulted in any reduction in such by-catch.

Faruque (2007), in his study of commercial *Pangasius* culture in Mymensingh District, Bangladesh, found that employment opportunities had been greatly enhanced in the last decade as commercial aquaculture became established. In particular, opportunities for agricultural day labourers appeared to have improved, inflation adjusted wages rising by around 50 percent and the number of days worked by 1.7 to 4.4/week. Fishers, in a context of diminishing opportunities for livelihood based on wild stocks, saw similarly improved wage rates, and there was evidence of large-scale entry into this activity by those formerly outside it. This contrasts with Ahmed and Lorica (2002) who, - undoubtedly referring to the “quasi-peasant” carp polycultures described by Belton, Haque and Little (in press) - observed that while there was clear evidence of positive income and consumption effects on households, employment effects were not significant. Belton, Haque and Little interpreted this outcome in terms of the limited labour demands of such systems. However, both more and less commercial types of aquaculture coexist in many areas of Asia and support a large network of ancillary services ranging from individuals and teams of poor people repairing ponds, harvesting, transporting seed and feed, and transporting and processing the outputs. Some may be highly specialized, such as the sludge divers who clean *Pangasius* ponds of sediment in Viet Nam during the culture cycle (Quach, 2008), whereas others may supply more generic services.

Improving understanding of aquaculture and poverty

A clear message and emerging consensus from research conducted in the last decade is that any analysis of the poverty impact of aquaculture has to acknowledge its variable importance within livelihoods of individuals and households and take a value-chain (Bolwig *et al.*, 2010) or “whole industry” approach (Beveridge *et al.*, 2010).

Initiatives to promote aquaculture towards poverty alleviation in the last decade have increasingly been based on the livelihoods framework (Ellis, 2000), acknowledging the concept of a diversity of asset type, the reality of diverse portfolios of activities and access to key resources as being critical for securing improved livelihood outcomes. Recognition of the importance of long-term trends of various types, and shocks and seasonality on peoples’ vulnerability has been mainstreamed among development practitioners and within the research and development (R&D) community.

Poverty and resilience

The resilience framework is showing potential to bring the linkages between social and ecological systems into a coherent framework in which efforts to

address poverty can be addressed, although the integration of social issues has proved challenging. Uncertainty and risk have been central to understanding livelihood responses to ecological, economic and political perturbations, as outlined above. The main line of thinking in the resilience literature towards social responses to change has been through an analysis of the capacity of a society or community (of aquaculture farmers, for instance) to self-organize. In doing so, the group can enhance opportunities to adapt to changing circumstances (Walker *et al.*, 2004). In turn, such collaboration may enhance the capacity to cope with uncertainty, the openness to learning, the acceptance of the inevitability of change, and the ability to treat any intervention as experimentation or “adaptive management” (Lebel and Anderies, 2006). The challenge then becomes to institutionalize the “adaptive capacity” within a socio-ecological system by supporting collaboration, pluralism and linkages between multiple types of stakeholders, diversity of interests represented, multiple perspectives on the problem domain, and connections across multiple scales and levels (Armitage, Marschke and Plummer, 2008). Resilient systems therefore not only have the capacity to maintain their functional interactions, but also the ability to adapt to external change and evolve through learning. This thinking underpins initiatives to establish and empower community-based organizations (CBOs) that can support social learning and adaptive capacity to better manage the aquatic resources central to the livelihoods of poor communities in Bangladesh and other shock-prone wetland-dominated environments (Demaine, 2010).

So, while there are structural sources of poverty as emphasized in early aquacultural social science literature (Bailey, 1988; Hannig, 1988; Stonich, Bort and Ovaes, 1997), the (social) resilience literature emphasizes the capacity of individuals and groups to institutionalize learning and adaptation to reduce their vulnerability to adverse changes. These issues are discussed later in this review with regard to applying the resilience concept to aquaculture value chains and as part of a livelihood portfolio in marginal agro-ecosystems.

Macro-impacts

An initial drive towards projects promoting aquaculture in “high-potential” agricultural areas has been commonplace, e.g. the Mymensingh Aquaculture Extension Project (MAEP) in which the areas selected in Mymensingh retained water throughout the year and had a high density of ponds (Rand and Tarp, 2009). The earliest established provincial fishery stations in Thailand were located in water-abundant areas. Naturally, such areas are relatively better endowed and likely to be more productive for agriculture *per se* (and indeed other value-added opportunities), making such areas better off. When aquaculture has been promoted in areas that are “poorer” and more marginal for agriculture, both the relative importance of aquaculture and the horizontal benefits (e.g. through improved water availability for surrounding horticulture) have been found to be more critical for alleviating the poverty of producers (proximate and related impacts) than better endowed areas. Promoting aquaculture in such areas,

characterized by greater abundance of perennial water resources and typically, wild stocks of aquatic animals, has often been less successful; in Cambodia a shortage of perennial surface water and related natural fish stocks in some provinces distant from the Great Lake and major rivers stimulated interest in aquaculture based on hatchery seed (Gregory and Guttman, 1996; Morales, 2007).

Agriculturally high productivity areas may be home to the greatest numbers of poor people; Minot and Bausch (2005) found that most poor people lived in areas of Viet Nam outside of the areas that had proportionally more poor. This makes the issue of targeting important; the Vietnamese Government recently chose to promote aquaculture actively in areas with higher proportions of poor (e.g. mountain and coastal areas) and yet immanent development of aquaculture through stronger commercial drivers has been rapid in the main delta areas. Belton and Little (2011b) have challenged the idea that project-driven interventions typically result in large-scale adoption and benefit for the poor. Instead, they claim that development in various forms typically drives entrepreneurial activity and the strongly commercial forms of aquaculture that develop result in large-scale benefits through employment throughout the value chain.

Sometimes aquaculture development projects, such as the Northwest Fisheries Extension Programme (NFEP), focused on a poorer region particularly deficient in wild stocks and undeveloped with respect to aquaculture infrastructure, such as northwest Bangladesh. Once the project had been initiated, however, it soon became apparent that private-sector networks were already well established (particularly with respect to seed supply), and the challenge then became to support them to benefit poorer stakeholders (Lewis, Wood and Gregory, 1996; Islam, 2002).

A long-term relative decline in the price of fish in markets is one important outcome of areas where commercial aquaculture has become established. Given the high income elasticity of demand exhibited for fish in much of Asia (Dey *et al.*, 2005), this means that poorer consumers particularly benefitted. This too has occurred in Egypt, where aquaculture has expanded from 50 000 tonnes to 700 000 tonnes between 1998 and 2008 and stabilized the source of fish, making it the most affordable source of animal protein for the poor.

Aggregate data on a regional or national level often lead to misinterpretation of the importance of aquaculture to local economies, as national aquaculture statistics are notoriously unreliable, and especially so for widely scattered small-scale farms (Bondad-Rentaso and Prein, 2010). Although aquaculture is considered important to the Philippines on a national level, the country featuring within the top-ten of global aquaculture producers (FAO, 2009), only 1 percent of the national labour force is employed. In contrast, tilapia culture contributes 50

percent of municipal income and employs 10 percent of the labour force in the Lake Sebu area of Mindanao (Hishamunda *et al.*, 2009).

The simple substitution of common-access aquatic natural resources by privately owned aquaculture has rightly been identified as a mechanism through which poorer people dependent on natural stocks can suffer directly through loss of access to a key food (Islam, 2009; Adduci, 2010). Furthermore, poorer people may suffer indirectly through impoverishment of other aspects of their livelihood. Such impacts may range from reduced agricultural productivity through salinization effects on crops caused by inland saline shrimp production (Goss, Burch and Rickson, 2000) to reduced quality of freshwater for the neighbours of catfish production and processing in Viet Nam linked to effluents (Quach, 2008; Anh *et al.*, 2010). Much greater productivity and employment benefits are often used as rationale to legitimize support for such transformations, for example, from mangrove to shrimp, that involve changes in tenure and often disenfranchisement (van Mulekom *et al.*, 2006). Intensified management of common property also has a mixed record in terms of success. In practice, group or “community”-focused support often delivers only short-lived benefits, entirely fails to live up to expectations of the participants, or actually creates or exacerbates conflicts among those involved.

The substitution of open-access but low-yielding, biodiverse aquatic commons into more intensive productive entities has a mixed record reflecting both practical constraints and prevailing cultural norms. Local organizations may have quite variable capacities to support adaptive learning and ensure that access to, and governance of, the resource remains inclusive and poverty oriented. In Laos, the relative success of stocking and management of common-pool resources which reflects efforts to ensure adaptive management has been core to the development effort (Arthur *et al.*, 2010). In contrast, developments in Bangladesh have been more uneven. While Valbo Jørgensen and Thompson (2007) documented successful socio-economic impacts for the poor, partly achieved through long-term consensus building (Sultana and Thompson, 2004) and a variety of other tools critical to achieving positive impacts of the institutional transformation of managed common-pool resource, others (e.g. Toufique and Gregory (2008) in their case study of floodplain aquaculture) found that in spite of attempts to protect the access and rights of poorer stakeholders, elite capture and exclusion of the poor had occurred. Hallman, Lewis and Bugum (2003) found that promotion of group-focused pond aquaculture among women in Bangladesh resulted in lasting embitterment because of the failure of the collective action required.

Adger *et al.* (2002) described the situation of coastal shrimp farming in Viet Nam as resulting in poorer fishers’ livelihoods being negatively impacted and reduced social resilience; similar reports have arisen elsewhere in Southeast Asia (e.g. in the Philippines, Primavera, 2006). Flaherty, Vandergeest and Miller

(1999) detailed the specific perceived negative impacts in rice growing areas of the introduction of inland shrimp farming in Thailand. Over a longer time scale, many of these fears have been assuaged; Belton and Little (2008) detected that unsustainable shrimp development in parts of central Thailand have underpinned the evolution of more sustainable forms of aquaculture over the longer term as entrepreneurs and farmers have demonstrated adaptive learning on a broad scale. Islam (2009) describes the phases of resistance, ambivalence and normalization for shrimp culture in the semisalinity zone in Bangladesh as local people have gradually perceived greater benefits of the changes from rice to shrimp farming.

Farming seaweeds for carrageenan is a popular alternative livelihood approach that has been introduced into several tropical developing countries to provide income for poor coastal fishing households (Sievanen *et al.*, 2005). Initially developed in the Philippines, it has been introduced into Indonesia, which is now the world's largest producer, and has been introduced from Asia to coastal regions of Tanzania (Rice *et al.*, 2006). The majority of the product (90 percent) enters the global value chain for carrageenan, an ingredient in foods and other products, that has grown at 5–7 percent per annum. Seaweed farming certainly has many positive attributes (e.g. see Msuya, 2009), but the producers may be particularly vulnerable to exploitation with boom and bust cycles.²

Towards well-being

Well-being, as opposed to income or “wealth”, has emerged as an important approach to distinguishing “experienced”, economic and income poverty (Rojas, 2008).

To paraphrase White and Petit (2004) “does more aquaculture development mean greater well-being?” Such a question begs the questions what is well-being and how can it be measured. Well-being has been related to three sets of issues “having”, “doing” and “thinking” (White and Petit, 2004). The “thinking” questions, i.e. how people assess and value aspects of their lives, how they prioritize and “join up” the various strands of their lives, complement a livelihoods approach that focuses on the assets, access and activities embodied in the other two aspects. The “being” in the term stresses the importance of security, both physical and economic, but also underlying social relationships and the “state of the mind”. These aspects are critical because there may be real conflicts between wealth generation *per se* and enhancing well-being, e.g. the trading off required by households of their young female members migrating to work in seafood processing factories and supporting rural households with remittance income compared to “losses” in other values. The studies of Bouahom, Douangsavanh and Rigg (2004) of the dichotomy occurring

² Presentation by I. Bryceson on *Linkages and interactions between fisheries, aquaculture, aquatic ecosystem health, human poverty-wealth and human health* presented at the 7th Asian Fisheries Forum, 2 December 2004, Penang, Malaysia.

between generations in Lao villages based on migration for work and the urban pull and that of Rigg *et al.* (2008) on the impacts of the reconfiguration of rural space occurring in parts of central Thailand on well-being related to modernity encapsulate some of these contradictions.

Well-being stresses the positive and avoids the stigma that can heighten tensions between better off and poorer in any community. The NFEP “village fish pond” approach (Islam, 2002) sought to diffuse tensions by targeting whole communities for support rather than only poorer households within them. Increasing social status through successful adoption of aquaculture even when financial returns remain limited may be critical: “According to Anil, a member of the Garo Adivashi tribe in Bangladesh ‘success of pond culture earned him respect in the community, with Adivasis and Bengalis alike coming to him for advice on fish culture’” (Barman, 2009).

Haque *et al.* (2010) found that the motivations for irrigated rice farmers adopting and retaining the production of seed and food fish in ricefields were multifactorial and poorly explained by dominant factors (i.e. availability of land and broodfish), reflecting the versatility and utility of the activity. Rainfed pond-owning farmers in northeastern Thailand rarely optimized fish production but valued the multiple products and services that an on-farm perennial water source supplied in such a seasonal marginal agro-ecosystem (Little *et al.* 2007). Important among their reasons were the improved availability and convenience of food and medicinal products once obtained from the wild and the satisfaction of growing food uncontaminated with pesticides, all of which heightened their sense of well-being.

Non-financial exchanges, especially the gifting of fish to neighbours and extended family, were found to be relatively more important in poorer areas of Bangladesh than the better off (Haque *et al.*, 2010). The practice was highly important among extended kin networks of pond gleaners in Manila Bay, Philippines, particularly the old and infirm, who were unable to participate themselves (Parker, 2008).

Improvements to the absolute standards of living of the largest and poorest rural group in Bangladesh, agricultural day labourers and fishers, have occurred in areas of commercial aquaculture development. Most (90 percent) of fishers, now working in harvest teams contracted by *Pangasius* farms to thin out and harvest fish in Trishal, Mymensingh, Bangladesh, improved their household food consumption since fish farming became established in the area and were satisfied by improvements in their overall standard of living with regard to clothing, housing and healthcare (Faruque, 2007). Ito (2002) questioned if the gains made by such poorer actors as a result of expansion in *Macrobrachium* culture in parts of Bangladesh were sustainable, noting a tendency for migrants to take local peoples’ jobs over time and for womens’ employment to be particularly low paid and hazardous.

The roles of aquaculture in improving human welfare can therefore certainly exceed monetary values and range from enhanced self-confidence and self-worth to stabilizing and sustaining the natural resource base. The rationale for a farming family or a family without land to become involved in aquaculture is based on multiple factors, the drivers for which are typically linked through positive feedback mechanisms. Fundamental to these are improved availability of food and security of access to food of high nutritional quality in the face of seasonality and environmental and economic shocks. Total or partial self-sufficiency by the household or access to purchase locally produced fish are typically highly regarded where fish has an important cultural value; quality, particularly freshness and convenience of fish supply are highly regarded.

Food security and consumer entitlements

Background

Food security has been defined as “all people, at all times, having physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 1996). However, recent food shocks have focused policy-makers in some countries towards ensuring food security as a national goal, and its use has often become confused with self-sufficiency (Economist, 2009). Food sovereignty, the concept that a given country has enough resources to make available food demanded by its people, irrespective of its origin, has become the practical “norm” for governance of food systems in many countries. However, the term has more recently been associated with the growing food sovereignty movement that advocates greater local control of food production and freedom from the organized power of science, business and mainstream politics in agriculture (Pimbert, 2006). In contrast to the use of the term food security at national and global levels to focus on the supply side of the food system, its greatest value is probably as a measure of household and individual welfare in combination with assessments of household food acquisition and allocation behaviour (Pinstrup-Anderson, 2009).

Food is often shorthand for “dietary energy”. However, food availability does not guarantee access, and enough calories does not ensure people consume a healthy and nutritious diet. Hence the emphasis in the FAO definition on nutritional value and the inclusion of the concept of nutritional security. The addition of “food preference” also changed the focus of security towards socially and culturally acceptable food.

At the household level, the idea of food security has been used as a measure of welfare and focus for development (Pinstrup-Anderson, 2009). Food insecure households cannot meet the needs of all members either on a permanent (chronic insecurity) or transitory basis; the latter normally relates to periodic shortages often relating to seasonality. In practice, seasonality in availability

of fresh fish, and/or variability in capacity to preserve aquatic animals can undermine “fish security” in a range of contexts. Variation in the intrahousehold allocation of food, however, can mean that individuals remain malnourished although the household as a whole is food secure; this is particularly prevalent in some cultural contexts. Even when access to high-quality food is possible for all individuals, a range of other non-food factors such as sanitation and health care can influence its nutritional impact. The necessity to integrate food and nutritional security is clear, since ill health related to micronutrient imbalance has been identified as a greater problem than hunger in achieving the MDGs (Shetty, 2009). The relative success of promoting aquaculture to support dietary diversification rather than alternative approaches such as biofortification also needs analysis. The nutritional significance of the poverty trap has been identified as a key element because of the power of the positive feedback linkages that nutritional status has, especially on the well-being of the most vulnerable. Access to quality food (and water) may be the single most important requirement to escape poverty because of the positive feedback associated with nutritional status and potential for other development.

The contribution of smallholder aquaculture to food security has been another important aspect of its promotion (Prein, 2002). The broader aspects of aquatic food security are first considered before implications for expansion of fish production either displacing or complementing other food production are considered. The potential nutritional impacts of replacing wild with farmed fish are discussed before the changing roles of farmed fish in diets, particularly of poorer people, are examined. The implications for the pond on a farm acting as focus for agricultural and nutritional diversification and methodological issues in their study are assessed. Finally some of the potential negative impacts of aquaculture on food security are reviewed.

Broader aspects of food security

The implications for aquaculture on food security cannot be divorced from supplies from capture fisheries, since they typically enter the same markets and are often indistinguishable. The politics of aquatic food security at the national level is demonstrated by countries such as Japan that enjoy high levels of per capita consumption and cultural attachment to fish in the diet (Smith, 2008). Japan has had long-term policy to achieve food “self-sufficiency” through expansion of its fishery sector and negotiation of international arrangements to reduce the economic burden of importing its necessary supplies. In common with other wealthy but food-poor states, Japan has long looked to become aquatic food secure, and in recent years has increasingly augmented fisheries with investment in and/or purchase of farmed fish and shrimp from poorer countries (Hall, 2004). The European Union (EU) is similarly dependent on importing fish from third, often less-developed countries (NEF, 2011). This position has effectively undermined the aquatic food security of many poorer countries. China, having rapidly increased consumption of livestock (including

aquaculture) products in the diet in recent years, has an alternative strategy, i.e. to exceed its food self-sufficiency requirements through importing feed ingredients and through a range of technological innovations to increase its production of farmed seafood (Zhao *et al.*, 2008).

There are many other threats to aquatic and broader food sovereignty and security for poorer countries, however, including the impacts of broader development that damage natural resources. In the rush to extract energy and mineral wealth, often in partnership with regional powers, poor states such as Lao PDR which are heavily reliant on aquatic food, are undermining their food security and urgently need to invoke the precautionary principle around the fundamental importance of food (Fullbrook, 2010).

The implications for sustaining local production and consumption of aquatic foods under pressures of global seafood markets are considered later in the review.

Quality vs quantity

The prioritization at international and national levels of “calorie security” rather than food security in the holistic sense remains problematic. The case for optimizing grain production through intensification over nutritionally more valuable food stuffs inevitably imposes a trade-off, particularly given shortages of water and land. This has been documented for the relative lack of focus on development of pulses in South Asia (Negin *et al.*, 2009) and is clearly the case for impacts on wild fish stocks in Asia.

In contrast to many other foods, fish and other aquatic products harvested at the community and household levels often contribute to daily subsistence, but the productivity of the system is sensitive to changes in agriculture, particularly water management practices. “Poor in all but fish” (Gregory and Guttman, 1996) makes the case that at low levels of rice production, typically in rainfed agro-ecosystems in Southeast Asia, rural people essentially support their subsistence needs for fish (and thus high-quality food) through managing wild stocks in and around their rice fields. Irrigated agriculture, in which flood control is introduced, historically has been followed by a rapid decline in such natural productivity. Lower yields of a wide diversity of aquatic products are the direct result of pursuing higher yields of rice.

At a more fundamental level and in contrast to many other food products, fish and other aquatic foods are still obtained from natural stocks at community and household levels, but these are increasingly managed to some extent. However, the productivity of these systems is sensitive to changes in agriculture, particularly water management practices. Nguyen Khoa *et al.* (2005) assessed the impacts of irrigation on ricefield-based fish production and found that wet season and large-scale off-farm managed irrigation systems were more likely

to be detrimental to the productivity and diversity of wild stocks than small and medium-scale structures on or near farm, for which impacts were generally benign.

Expansion of aquaculture at the expense of rice fields, while considered a positive diversification of the rural economy in many quarters, is considered to be a threat to grain self-sufficiency and rationale for limiting expansion of fish pond construction by others. On a macro-level, it may strengthen the case for promoting the integrated production of rice and fish, since in addition to benefits such as reducing pesticide use, multiple land functions are retained and more balanced nutrition likely (Halwart, 2006).

Pond construction has often been a by-product of house and road construction.³ Large expansions of pond construction have occurred in some geographical locations over very short periods of time. This has often been in areas that were low lying and relatively unproductive but has also included the use of high-quality agricultural land, with implications for production of staple grains and other forms of diversification.

In tandem with this has been a process of aquaculture intensification, particularly through the use of increased supplementary feeding and formulated diets that has in some cases resulted in land use for aquaculture either not expanding very fast in recent years or actually contracting. These trends are particularly clear where the cost of land rental has risen fast, for example in some peri-urban areas or where clusters of commercial aquaculture have become established.

Implications for farmed fish substituting for wild

There are potentially important nutritional implications for any change in human diets based on a shift from wild fish to farmed fish. Farmed fish fed on supplementary and complete diets tend to be higher in lipids than wild fish, even of the same species. For rural diets traditionally deficient in fat, it can be speculated that this may be highly advantageous where chronic protein-energy malnutrition remains common in vulnerable groups.

The quality of fats, a key element that fish bring to rice-based diets in addition to high-quality protein, is likely to change. Generally with intensification, studies have shown ratios of the critical highly unsaturated fatty acids (HUFA; W3:W6) decline and become less optimal. Karapanagiotidis *et al.* (2006) found that wild tilapia had more optimal ratios than fish raised intensively in cages (with fish raised semi-intensively more variable, depending on the specific method of production). The same authors (Karapanagiotidis *et al.*, 2007) also showed that

³ Presentation by D.C. Little, N.R. Biswas, B.K. Barman, M.M. Haque, D. Turongruang, A. Shinn, M.A.R. Hossain, P. Price, G. Milwain, E. Morales, Z.F. Ahmed & F. Ul Islam on *Enhancing aquatic diversity while promoting aquaculture among the poor – 'win-win' development in Asia* presented at World Aquaculture 2009, September 25–29, World Trade Center, Vera Cruz, Mexico.

the composition of farmed fish could be modified through change in the diets fed. Widespread substitution of wild fish by farmed fish with suboptimal lipid profiles to feed urban populations could exacerbate the nutritional impacts of changing diets. The widely believed generalization that pellet-fed fish are more expensive and less affordable for poorer consumers than those from semi-intensive systems is, in some cases, no longer true. Intensively raised pellet-fed *Pangasius* is now one of the cheapest fish available to poor consumers in Bangladesh, while semi-intensively produced carps are much more expensive and often beyond their reach (Belton, Haque and Little, in press).

Fish are nutritionally important in many rice-based diets through their micronutrient content and, importantly, their bioavailability. Vitamin A, calcium, iodine, iron and zinc are known to be important (Roos, Thilsted and Wahab, 2002; Roos, Thilsted and Islam, 2004). Research by Roos, Thilsted and others has established the potential nutritional impacts of substitution of small indigenous fish by farmed fish. Impacts are related not only to differences in the nutritional content of different species but also to how their size and taste affect preparation and consumption. Thus, the particularly high vitamin A content of mola carplet (*Amblypharyngodon mola*), especially concentrated in the eye, its small size and likelihood to be consumed whole optimizes intake of this vitamin and calcium, since the head, eyes and soft bones of small fish are also typically consumed. In contrast, farmed species eaten at a larger size tend to have much lower levels of micronutrients. In another study, Roos, Thilsted and Wahab (2002) suggested that regular consumption of small fish met 40 percent of vitamin A and 32 percent of calcium needs during the peak fishing season of poor rural families in Bangladesh. A major issue is that wild fish often attract a premium in the market and cultured fish, often of relatively small size, have now become cheaper, more available and thus a mainstay of poorer peoples' diets (see footnote 3).

Farmed fish – roles in the diets of the poor

Access to farmed fish by the poor is highly context specific. The increasing numbers of urban poor are mainly dependent on purchase from markets, although open-access urban waterbodies, typically highly eutrophic and productive, may also be important sources. The rural poor were traditionally and, in many cases still are, dependent on wild fish for meeting their dietary needs. In areas with a strong wet:dry seasonal pattern, this has always imposed constraints on the availability of fresh fish, often leading to a strong cultural reliance on, and affinity for, processed forms: fermented, salted and dried.

Promoting smallholder aquaculture has often been based on the premise that this results in fish farming households eating more fish (Ahmed and Lorica, 2002), but there has been little research to correlate increased production, resultant levels of consumption and impacts on household nutritional security. Rural livelihoods in Southeast Asia are still mainly based around the production

of rice and aquatic animals, both stocked and unstocked, which are increasingly managed as an intrinsic part of the system.

A three-country study in the region that evaluated the roles of farmer-managed aquatic systems (FMAS) in two agro-ecological settings (i.e. low-lying, flood-prone and higher, drier sites) found that better-off and poorer households sourced aquatic animals from four major sources, namely FMAS, open-access waterbodies, the market and as gifts (Morales, 2007). This study found large differences in dependence on stocked hatchery fish compared to non-stocked fish, with poorer households being relatively more dependent on small household ponds than the better off. In contrast, Belton, Haque and Little (in press) found that the better-off households raising carps in ponds in Mymensingh, Bangladesh, were less food insecure than the general population and that the impact of consuming self-produced fish on their food security was probably less significant because of their ability to access fish from the market and elsewhere.

More recent interviews to understand consumption habits of some of the poorest people in Bangladesh by Barman *et al.* (unpub.data) found that for female-headed households employed as brick and stone breakers, expenditure levels on basic foodstuffs exceeded 90 percent of income. Unable to catch fish themselves, the limited amount of fish they consumed was purchased as cheaper small wild or farmed fish, with trends in consumption towards the latter. Milstein, Kadir and Wahab (2008), as part of their research in polyculture development, reported on the interest in small silver carp (*Hypophthalmichthys molitrix*) by poorer farmers “because they can afford to eat rather than sell”. This sentiment has been found widely among poorer households managing to stock fry (that are increasingly affordable and available) and manage self-recruiting stocks of tilapia and a variety of unstocked indigenous species in small ponds, ditches and rice fields that they can access.

Barman Little & Edwards (2002) found that over several decades tilapia had become established in the patchwork of perennial and seasonal ponds of northwestern Bangladesh as a “silent harvest”. It was recognized as a “local fish” because it was too small and too low in value to be worth marketing (principally by men) but easily accessible by women and children by angling.

Production and even consumption, rather than sale of fish produced in small-holder systems, does not necessarily result in those most requiring high-quality nutrition accessing it. Intrahousehold fish consumption patterns are strongly related to gender and age in Bangladesh. Thus, nutritionally vulnerable adolescent girls, whose nutritional status affects not only their own but future generations’ capacity for development, may have far poorer diets than males of the same age and other household members.

Haque *et al.* (2010) identified a wide range of factors that made the low-cost, low-risk entry into ricefield-based tilapia culture a net benefit for poorer rice farmers in northwestern Bangladesh, subject to certain conditions. Despite their value as seed fish, small tilapias were highly valued as food; their convenience and accessibility appeared to have particularly supported consumption by some of the more nutritionally vulnerable household members, the young, old and women.

Recent studies (Morales, 2007; Haque *et al.*, 2010; Karim *et al.*, 2011) revealed aquaculture to be a coping mechanism for poorer farmers' security in a number of ways, providing both quality food and income but also allowing investment in both human and social capital. In studies of more commercially oriented nursery operations in neighbouring West Bengal, Barman (unpub) observed the land-poor people involved operating such high-input:high-output systems through lease arrangements. In such cases, cash may be used to purchase cheaper foods. Several studies have shown that fish producers often continued to buy and/or catch fish from natural sources for much of their needs (Karim, 2006; Faruque, 2007; Morales, 2007; Kawarazuka and Bene, 2010). This is typically strongly variable from season to season and year to year, with periods during the wet season when consumption is still dominated by the wild catch of ricefield fish. Farmers may be strategic in their behaviour towards managing their on-farm water resources. In Cambodia, farmers only showed interest in stocking hatchery seed when early rains were poor and wild fish yields were expected to be low (Gregory and Guttman, 1996).

Methodological issues

There are numerous methodological constraints to understanding food security and the supporting role of aquaculture. Determining household size and per capita consumption, and their interpretation in terms of poverty, is beset with practical problems and interpretation issues (White and Masset, 2003). High levels of seasonality of access to, and consumption of, fresh aquatic foods are common, necessitating costly repeat measures. Intra-household perceptions of food insecurity can be quite variable, particularly where food-related responsibilities are strongly related to gender. There were significant amounts of discordance between genders regarding the perception of food insecurity in Bangladesh, with women far more than men, claiming that a consumption reduction strategy that included not eating "big fish" to be important. This illustrates the necessity for individual-level and age and gender-specific measures to complement household data and for proportionate representation of vulnerable individuals (Coates *et al.*, 2010). The recall of fish consumption information, even when supported with broader dietary data, is often piecemeal and uninformed by type, size and source (i.e. purchase, self-catch or gifting) or information regarding preparation and actual consumption data. In this context and especially where household-managed systems are used as day-to-day sources of food, reliable estimates of intra-household consumption are often lacking.

Claims made as to the importance of specific nutrients (e.g. iron or vitamin A) need to be assessed in the context of whole diets. Estimates of fish consumption alone are, therefore, quite limited in determining the nutritional impacts of increasing fish production and consumption. In recent years, the promotion of smallholder fish culture has often come as part of an integrated package as promoters have increasingly advocated building linkages between the fish pond as an on-farm reservoir and surrounding horticulture. Such integrated aquaculture-agriculture systems (IAAS) have often aimed to improve household nutrition and generate income, and these are now assessed.

Impacts of water and nutrients from fish ponds on broader food security

Ponds often have a key or principle role as an on-farm water source rather than for fish production, particularly in marginal rainfed agro-ecosystems. This may even be the case where ground water exists but pumping costs preclude its economic use. Where fish production was not a key focus in pond construction, its role in food security therefore requires broader interpretation. Development initiatives have often promoted fish and vegetable production because of the presumed synergies and expected greater efficiency of land and water use. Such systems have also been a key part of traditional Asian IAAS, such as the integrated mulberry dyke system in the Pearl River Delta, China (Ruddle and Zhong, 1988) and VAC systems in Viet Nam. The role of aquaculture in terms of overall food nutrition often begs reassessment, especially with regard to consumption of other quality dietary items increased as an outcome of such IAAS.

In an assessment of impacts of aquaculture and vegetable promotion projects in Bangladesh, Hallman, Lewis and Bugum (2003) found that “at risk” groups (i.e. school-age children, adolescents and older adults) in adopting households had a larger share of calories derived from green leafy vegetables. Adolescent girls, who are both nutritionally and socially vulnerable, consumed more total calories in adopting households and, in general, school-aged children and adolescents in adopting households were slightly taller. Preschoolers and older adults in adopting households had less acute and chronic illness.

Promotion of IAAS in Malawi has also demonstrated the nutritional significance of on-farm pond-based diversification for improving household well-being. While fish yields have remained low, mainly due to limited on-farm resources for pond nutritional inputs and a lack of availability of external inputs required to enhance productivity, farming households used pond water to support vegetable production for sale and consumption (Brummett, Lazard and Moehl, 2008; Dey *et al.*, 2010).

Karim *et al.* (2011) observed important differences in consumption among rural and peri-urban located pond-owning households in Bangladesh, suggesting their different strategies. Whereas rural households consumed relatively more of their

own fish and vegetables, those located closer to urban centers produced more of both and tended to sell more and eat less themselves. The context of food item substitutability is clearly different, with market purchases being relatively more important for those located closer to urban areas. Few differences were found for better-off and worse-off households in production or consumption of fish or vegetables, but this might reflect the limited distinction between the groups in terms of agricultural assets; an analysis of purchasing behaviour found significantly lower overall expenditure in the poorer group (Karim *et al.*, 2011).

Potential negative impacts of aquaculture on food security

Aquaculture has been identified as a major route through which poorer people with few assets are denied access to common-pool fisheries on which they have great dietary reliance. Such developments have been observed for both coastal and inland environments, as the returns from commercial aquaculture have led to resource grabbing by elites, whether locals or outsiders (e.g. Stonich, Bort and Ovaes, 1997; Vandergeest, Flaherty and Miller, 1999; Islam, 2009; Adduci, 2010). This is undoubtedly an area of major controversy and research need given the multiple stressors that common-pool resources face. There is evidence that aquaculture in areas with a previous high dependence on fishing by the poor, such as in ghers (trenched rice fields) in Jessore, Bangladesh, has resulted in greater employment and social mobility (Faruque, 2007), but there is also evidence to the contrary (e.g. Ito, 2004). Livelihood diversification through aquaculture value chains, whether domestically or internationally driven, undoubtedly leads to higher employment, but the quality and sustainability of such employment of the poor in many instances requires further research.

The indirect loss of access to small wild fish by poor people as they are increasingly sourced as feed ingredients for cultured fish is another important potential threat to the food security of vulnerable groups. This appears to be a transitional arrangement in many cases, however, as once a significant demand for feed is in place, private-sector feed producers, often diversifying from poultry feeds, tend to begin supplying the demand. The trend toward use of formulated diets, of course, may merely shift the impacts, both environmental and social, towards the world's declining industrial and artisanal fisheries (Hasan and Halwart 2009). The high value of small wild fish to local people appears to have raised its value, making its use as a fish feed uneconomic in some contexts (Hambrey, Edwards and Belton, 2008; Hasan and Halwart, 2009). There is some evidence that this means that the poor lose access, however (see above).

There may be qualitative impacts on an increased proportion of farmed versus wild fish in the diet (see above) but equally, the control that farming allows can reduce certain nutritional risks that consumption of enduring wild stocks pose. The contamination of wild fish through industrial dumping led to high levels of dioxin and other persistent compounds in wild fish in Viet Nam (Minh

et al. 2009), causing serious public health impacts that are still evident. Such contamination risks from farmed fish are, theoretically, more avoidable but remain a major issue in terms of improving traceability and trust.

The widespread occurrence of foodborne trematodes (FBTs) in certain parts of Asia makes the promotion of further fish consumption through aquaculture potentially a risky strategy if such fish are not well cooked before consumption (Phan *et al.*, 2010). Studies have shown that both wild and cultured fish were at similar risk from infection currently at the sites in northern Viet Nam (Phan *et al.*, 2010), but that given management safeguards within culture systems, these could be reduced for farmed fish. Any relatively greater reliance of the poor on wild and farmed fish may therefore pose differential risks and requires further investigation.

Concerns are regularly raised about contamination of food chains for all farmed livestock including fish. Some of these relate to purposeful attempts to reduce feed costs through adulteration, such as the use of melamine (Anderson *et al.*, 2011). Others involve accidental contamination such as that which caused unacceptably high levels of dioxin in eggs and milk. In Egypt, there are concerns that the law, which proscribes use of any surface water for aquaculture other than agricultural drainage water, may increase risks of contamination of farmed products with pesticides and metals. Other potentially significant indirect mechanisms for a decline in overall food security include the loss of environmental resources and reduction in water quality associated with poor disposal of aquaculture effluents. Groundwater extrusion for intensive aquaculture resulting in salinization of aquifers remains a risk to peoples' well-being in many semisaline zones. The need to purchase bottled drinking water by residents downstream of intensive *Pangasius* production in the Mekong Delta (Quach, 2008) is likely to disproportionately impact poorer people. Both require careful regulation, which is notoriously difficult in LDCs with rapidly growing, dynamic and geographically dispersed aquaculture. The maintenance of public health safeguards under such conditions appears likely to become polarized between products destined for domestic consumption and international markets that are becoming increasingly subject to various forms of certification and oversight (Broughton and Walker, 2010). This raises the issue of how the globalization of aquaculture value chains may potentially benefit or adversely affect the poor which is considered in the next section.

Progress, opportunities and improvements – aquaculture as a driver for development

Local and global aspects of aquaculture development

The last decade has witnessed a massive expansion in export-oriented aquaculture, but the vast majority of aquaculture production in LDCs remains for domestic consumption. Even the recent history of massive export growth

in China is dwarfed by the significance of its rapidly growing domestic market (Broughton and Walker, 2010; Little, 2010), much of which is carps with little potential for export. There is, however, a significant regional trade in Indian major carps between South Asian countries and the Middle East and Europe for migrant workers. In terms of impacts on poverty, the effects of changes in demand for farmed fish within producer LDCs, often linked to urbanization, are likely to have more impact. Given comparative growth potential and expected changes in purchasing power together with trade governance mechanisms being developed, this is unlikely to change greatly in the future.

The rapid demographic and accompanying settlement changes evident in some of the key LDCs in which aquaculture has grown rapidly explain many of the changes in the field. Rapidly escalating demand for cheap, usually freshwater, fish to feed migrant workers in cities as far apart as Delhi, Lagos and Cairo has been an important early driver of growth in commercial production and marketing networks, but there are now a number of second and third generation developments underway. Often centers of production are located in essentially peri-urban areas and/or along development corridors such as Dhaka-Mymensingh in Bangladesh or Hanoi-Hai Duong in Viet Nam.

In Nigeria, intensive culture of North African catfish (*Clarias gariepinus*) in and around urban centers is a growing success. In contrast to the problems that constrain aquaculture development generally in sub-Saharan Africa (Brummett., Lazard and Moehl, 2008), both high-quality seed and feed are available from a competitive private sector, and unfulfilled demand from urban markets is driving demand from the 5 000 or so commercial enterprises in operation (Miller and Aleem, 2010).

In Southeast Asia and other areas where fish is a preferred food, people tend to both consume more fish as they become wealthier and demand greater variety. This is confirmed in many of the national consumption surveys around the region (Delgado *et al.*, 2003). This, in turn, drives diversification of demand and in turn, production by farmers. The migration of rural populations to urban centers appears to have stimulated what might be termed “cuisine shifts”, where once low-value rural foods are now in higher demand. The (cultural) value of wild-caught riverine fish has certainly increased as a result of becoming more scarce, leading to higher cuisine-led demand in urban centers, creating a higher demand for alternative, indigenous species to which farmers have responded. The promotion of the various high-value catfishes and carps (Mekong giant catfish (*Pangasianodon gigas*) and *Hemibagrus wyckioides* are being cultured in Thailand, and stinging catfish (*Heteropneustes fossilis*) and pabda catfish (*Ompok pabda*) in Bangladesh) are good examples, as are the recent development of climbing perch (*Anabas testudineus*) in the same country. This can have other impacts. There is now an established market for silver carp previously raised only for direct human consumption as a feed for Chinese softshell turtle (*Pelodiscus*

sinensis) and other carnivorous species raised in the Red River Delta, Viet Nam, for the high-value Hanoi market. Demand for the same and other turtle species in China, some of them endangered in the wild, has reached massive scale (Haitao *et al.*, 2008), with implications for sourcing appropriate feeds.

Urbanization can have impacts on the development of aquaculture in rural areas, through influencing acceptability of novel species and their preparation. The widespread acceptability of small deep-fried tilapia by rural migrants in urban Thailand has undoubtedly impacted on its popularity in rural areas over time as migrants have returned home (Little and Bunting, 2005), illustrating the influence of rural-urban linkages.

Regional markets, particularly trade between neighbouring countries, have long been a feature of fishery marketing systems in LDCs. Aquaculture products have now become well established, especially as high-value live products (e.g. freshwater and brackishwater seed) and food that is often transformed as dried, salted or smoked products. These value chains afford opportunities for employment, often for poor people. Thus seed networks have been examined in some detail, with research showing the potential for poorer farmers to participate in nursing (e.g. Little, Surintaraseree and Innes-Taylor, 1996; Haitook, Kosy and Little, 1999; Litdamlong, Meusch and Innes-Taylor, 2002). However, other research indicates the multiplier effects, typically around ethnic and kinship linkages that develop and drive trade. Hence, displacement of Bengalis from Bangladesh during its liberation war to far-flung locations in western India, as well as to the major fish culture area in West Bengal, India, has led to transcontinental trade (by train) in freshwater seed. Similar trade typically carried out on a seasonal basis by poor people occurs between neighbouring states such as Bangladesh and India, Nepal and India, and Viet Nam, Laos and Cambodia. Live hybrid catfish from Thailand are traded far into Laos, but processed snakeskin gourami (*Trichogaster pectoralis*) have a much longer established trade throughout Southeast Asia, founded on one of the earliest occurrences of fish culture in Thailand.

Higher market value fish are sold live from mainland China to Hong Kong SAR. Subtle differences in climate within the region can also drive the market. The year-round production of soft-shell turtle, mainly on the eastern seaboard of Thailand, supported a lucrative trade in air-freighted live turtle to southern China for several years until trade restrictions were imposed. Expensive marine fish such as grouper, fattened from wild-caught juveniles by part-time fishers in southern Thailand, are sold to premium Chinese urban markets throughout the region (Sheriff, Little and Tantikamton, 2008). This system is a good example of poor marginalized communities being able to complement fisher livelihoods with high-value products through aquaculture. It is also an example of how a technical gap (i.e. the lack of hatchery-produced juveniles) can favour such disadvantaged groups. The pros and cons of technical changes that are characteristic of aquaculture on the poor are now considered.

Technological development and the poor

The high prices that poor coastal fishers who have adopted grouper farming in southern Thailand continue to enjoy (Sheriff, Little and Tantikamton, 2008) reflect the scarcity and status of the product. The constraints to hatchery production of grouper juveniles ensure that over-production is avoided. Fishers have a comparative advantage, as they are able to source wild juveniles and the trash fish needed to fatten them locally for the opportunity cost of their time. Poor shrimp and prawn postlarvae fishers in Bangladesh have been identified as a particularly vulnerable group (Ahmed and Troell, 2010) but appear much less secure, as their activities have been associated with unsustainable environmental impacts and banned. Probably more importantly, a competitive hatchery sector is now established that can supply demand more consistently, although hatchery postlarvae continue to be perceived as being of poorer quality than wild-sourced seed.

Although once established in the private sector, hatcheries and nurseries may have modest direct impacts on poor livelihoods (Belton, 2010), they can have considerable multiplier effects. Prior to the development of carp and catfish hatcheries in Asia, harvest and nursing of wild seed was a seasonal activity for people living close to major rivers. In these cases, development of hatcheries has permitted a vast scale-up of food fish production and ancillary networks. One study of a cluster of nursery enterprises in northern Viet Nam found that the number of nursery enterprises had increased from three in 1950 to more than 100 by 2000 (Prax *et al.*, 2000), with concomitant impacts on forward and backward linkages that tend to provide livelihood opportunities for poor people.

Edwards (2010b) has documented several case studies indicating the benefits to the poor as producers within the nursery sector in Asia from carps and tilapias in West Java, Indonesia, shrimp in Thailand to marine finfish in Bali, Indonesia. Some of these occur on a significant scale. There are reportedly 26 000 small-scale hatcheries owned by individual smallholder farmers or farmer groups using traditional technology to breed freshwater fish species in West Java. Studies including Little, Nietes-Satapornvanit and Barman(2007) suggest that expansion of the nursery sector away from hatchery clusters and closer to sites of grow-out could greatly benefit poorer actors, and this is considered below.

The technological barriers to entry to certain parts of the value chain by the poor have often been shown to be surmountable by innovative practice. Early hatchery designs were typically capital intensive and developed by engineers for the public sector. Once in the private sector, design and practice have often been simplified and costs reduced, leading to considerable local social learning and adaptation. Ponds and hapas have substituted for concrete tanks, use of surface water for deep tube well water and converted ricefields instead of lined ponds. The case of prawns and shrimp in Thailand serve as good examples of such farmer-level innovation (Kongkeo and Davy, 2010). A major threat to the enduring success

of the Thai small-holder shrimp hatchery sector is the increasing dominance of specific pathogen-free (SPF) broodstock and postlarvae that has developed based on imported brood shrimp. A paradox is that the disease-free postlarvae produced appear to have contributed in large part to the improved sustainability of shrimp production by both smaller and larger grow-out producers.

International markets for farmed aquatic products and the poor

The capacity that producers have shown in adapting systems to their own resources and local markets is now potentially challenged in terms of reaching and maintaining access to international markets. The challenge of smallholders responding to globalization has been the focus of an increasingly heated debate of the benefits to development of such trade and efforts to regulate it, particularly through standards setting and certification (Bush, Khiem and Sinh, 2009; Belton *et al.*, 2011a). Smallholders have largely formed the bedrock of the rapidly developed aqua-product export industries, but the degree to which they can either link into or stay connected to these dynamic markets is now determined largely by their capacity to comply with market safety and quality requirements (Beveridge *et al.*, 2010). They also remain vulnerable to market forces and politics, in addition to the “usual” environmental, quality and disease-related vulnerabilities. The recent history of trade in *Pangasius* between Viet Nam and the United States of America and, subsequently, Europe is sobering (Bush and Duijf, 2011) and indicates how value chains need capacity to adapt, often over very short periods of time.

The observation that aquaculture is perhaps more likely to benefit farmers who are able to negotiate access to higher-value market chains means that this category of farmer is also likely to increase his/her vulnerability to a wider set of (market) processes. This is in contrast to enterprises less exposed to such economic forces and for which environmental vulnerability may be more important. It also suggests that vulnerability in value chains might well be a more useful concept than poverty when assessing the potential of aquaculture in supporting the livelihoods of small-holder aquaculture farmers and those associated in ancillary services. The exposure of small holders to international markets through global value chains has in many instances increased their earning power, as well as their exposure to what for many are new forms of economic risk. In many value chains, smallholders are considered powerless to avoid exploitation. Marginal groups in global value chains are therefore often considered as being systematically disadvantaged within increasingly globalized relations of production (Nadvi, 2004). These groups may well be “poor” in either or both national or international “a-dollar-a-day” quantitative terms. However, more importantly, they are those who are restricted in developing the necessary capabilities to improve their livelihood by wider political, social and economic factors and relations of production (Bebbington, 1999). Following this logic, farmers who are labeled as “poor” are not the only vulnerable group in the context of global, regional or even domestic value chains.

As such, vulnerability may well prove a more useful analytical concept than poverty in understanding the marginalization of smallholder aquaculture farmers in value chains. Vulnerability provides a more considered appraisal of the contextual factors that determine the capability of producers to upgrade their position in value chains (Nadvi, 2004). Following Bolwig *et al.* (2010), we can use the concept of vulnerability to:

1. identify the dynamics, patterns, arrangements and processes that may lead to durable inequality and marginality;
2. understand the sensitivity of livelihood systems to external shocks and the factors that reinforce their resilience;
3. analyze the degree of leverage producers have to access and control resources in markets, change the terms of market access and respond to governance arrangements such as quality standards.

The vulnerability of farmers and other actors in such value chains is therefore derived from their capacity to negotiate the terms and conditions of incorporation into different value chains, in addition to their capacity to command control over the factors of production and improve production processes. A failure to do so on favourable terms results in what is known as “adverse incorporation” (Ponte, 2008). Farmers may also decide to “opt-out” or choose, dependent on their capability, to “upgrade”, “downgrade” or “outgrade” their production through engagement in alternative, or modified activities (Humphrey and Schmitz, 2004). In some cases, farmers may well be forced out of production, or decide to “hang in” with the hope of high returns at a later date (Dorward, 2009). Alternatively, they may be able to intensify production and in so doing negotiate better terms of incorporation in global markets (Dorward, 2009).

Many of these alternatives are associated with mitigating risk. For instance, some aquaculture systems in which the primary product is raised for export also produce significant secondary products with local value at both production and processing levels. Thus, freshwater prawn culture in Bangladesh producing tails for export typically occurs in polyculture with carps and self-recruiting species that are sold locally; this can diversify income for the producer and form part of the fish-catching team’s benefit. This situation is analogous to the co-production of an export crop such as coffee or cocoa with subsistence or domestic market-oriented crops in traditional home gardens; such systems are both ecologically and socially more resilient than monocultures, and many have potential for further improvement (Chandrashekhara, 2010). Potential strategies to support smallholders and other poor actors in negotiating their positions in value chains are discussed later.

The varied forms and scales of aquaculture now in existence suggest a relationship with poverty alleviation that can be defined by the level and scope of change in livelihoods. Strongly commercially oriented aquaculture can support radical and significant change to livelihoods at the household, community, regional

and even national level. In contrast, the uptake and adoption of aquaculture can also have impacts which are seemingly more modest and harder to quantify but which support incremental change at the individual, household or broader societal level.

Impacts on livelihoods – local and global options

Aquaculture that has occurred in Asia, the Americas, Africa and Europe and been linked to global export products such as salmon, shrimp and tilapia has had radical impacts on supplies of these products in the market and the livelihoods of those involved. However, it also relates to the much more heterogeneous commercial aquaculture that has emerged to supply growing urban domestic markets in Asia and elsewhere. Other characteristics of such radical change stimulated by aquaculture include the contexts where it has become a dominant source of income and major determinant of labour organization at the household or community level. This has occurred in a variety of ways, from the single corporate entity in a formerly poor area in Honduras producing tilapia intensively in cages and claiming to have transformed employment opportunities and well-being of significant numbers of local people, to fish seed production and marketing clusters in Asia that in recent decades have measurably improved livelihoods among the majority of inhabitants.

These types of examples are, through their very nature, relatively geographically concentrated. In the Mekong Delta, *Pangasius* catfish production has grown at an unparalleled rate and brought multiple benefits directly and indirectly, through production, processing and elsewhere in the value chain. Shrimp production has probably achieved similar change in parts of coastal Asia, over a longer time scale, but criticisms of negative social and environmental impacts (e.g. Skladany and Harris, 1992; Stonich, Bort and Ovares, 1997; Stonich and Bailey, 2000), once warranted, now need review and holistic reevaluation. The impacts on poverty through enhanced employment opportunities, particularly in the processing sector, still require comprehensive assessments, particularly from the view of overall well-being. Moreover, significant changes in production technology and management have reduced proximate environmental impacts in shrimp through much reduced effluents from low-water exchange shrimp production systems (McIntosh, 2010).

Barriers to poorer producers entering or staying in global value chains appear to be rising however, partly in response to the rise of private regulatory systems. Over the last decade, there has been a shift from quantitative to qualitative policies and governance. The most direct impact of such policies has been the rise of grades and standards through a variety of state and international voluntary certification schemes. The impacts of this shift have been manifold. The first point relevant to the present review is the impact this shift has had on small and medium-sized producers. A second related point concerns what “services” are being developed to support these farmers as they are drawn into (sometimes multiple) international regulatory networks over food safety

and quality, including social and environmental issues (Vandergeest, 2007). The evidence suggests that the cost of compliance with such standards greatly advantages larger, capitalist and corporate types of aquafarming and that the outcomes of various approaches to support collective action of smallholders are still unproven (see below).

In Asia, there are now several examples of how “boom and bust” aquaculture based on a single valuable crop (i.e. shrimp, *Pangasius*) can be followed, after an adaptive response at various levels, with the development of a more diversified and perhaps sustainable aquaculture. Such second or third generation forms of aquaculture may be more rooted in local markets and demand or continue to serve international markets. Belton and Little (2008) report on such a process in central Thailand for shrimp, and Loc *et al.* (2010) in Viet Nam record an interesting shift in production for smaller farmers producing shrimp and *Pangasius* for global markets towards lower risk, domestically traded species – tilapia, mudskippers, gourami and crab. The resilience and ability of producers to adapt are uncertain, and likely to be variable and relate to their broader livelihood asset portfolios. Labrousse (2009) reported the different outcomes of a decline in farm-gate price on *Pangasius* farms in the Mekong Delta, Viet Nam. Whereas smallholders retaining their orchards have been largely able to stay on-farm, many households who had completely converted to *Pangasius* were forced to find off-farm labour opportunities. While both types of farmers were forced to “step-out”, those with more diversified on-farm resources retained more options.

There are likely to be broader implications for the failure of a significant proportion of the current aquaculture industry to meet international standards. One scenario proposed for China is that a two-tier system will result in local, especially poorer, people missing out on independent oversight and products destined for local markets potentially becoming a source of contaminated food (Broughton and Walker, 2010).

There are other outcomes of aquaculture remaining and further developing a domestic market orientation. Belton *et al.* (2011a), in a comparison of Viet Nam (export oriented) and Bangladesh (domestic oriented), identify the latter as having greater pro-poor characteristics overall. The less intensive Bangladeshi production has relatively greater employment opportunities, enhances local low-cost food availability and is more resilient in the face of unstable international markets.

There are clear prerequisites for aquaculture delivering such radical outcomes to livelihoods in a given context. These include access to markets and input supplies, in turn typically related to functioning roads and other infrastructure. An effective legal framework and functioning land market are also necessary, although the large-scale adoption of commercial aquaculture has been questioned in terms of its impact on equity. While Irz *et al.* (2007) reported a positive impact on rural equity for coastal aquaculture in Pampanga Province in

the Philippines, despite ownership of land being highly skewed, in Bangladesh aquaculture may have the opposite effect in some instances (e.g. Toufique and Gregory, 2008). In some areas where land costs have increased sharply in response to commercial aquaculture becoming established, poorer farmers lacking in capital opportunities to develop ponds themselves gain more through higher lease incomes than is possible from rice cultivation and diversification to other livelihood opportunities.

Incremental change to complex livelihoods through aquaculture

Aquaculture has also impacted on poverty and well-being through incremental change despite forming a relatively minor part of livelihood portfolios in some instances. This may relate to seasonal employment or returns from production constituting less than 50 percent of total household income, often much below. Belton *et al.* (2011b), in a meta-analysis, found that most “quasi-peasant” aquaculture in Bangladesh made up less than 15 percent of total household income. Similar results have been found elsewhere in Asia (e.g. Morales, 2007). Motivations for adoption and retention in the household’s portfolio of activities typically relate to a range of continued, often qualitative, benefits. Many of the advantages associated with smallholder aquaculture may relate to its complementarity to overall household labour use. Inputs are typically modest during the culture cycle, and contracting out of labour-intense activities is a common practice, especially at harvest.

Pond-based culture may be complementary with incentives to store water on farm as a multipurpose resource, particularly in a strongly wet:dry climate, considering that fish production within on-farm water management strategies is an increasingly important aspect of agriculture in areas of inconsistent rain-dependent marginal agriculture. Despite the examples of more commercially oriented aquaculture and the most productive agriculture being developed in “high-potential” areas in Asia, LDCs generally remain heavily dependent on rainfed production; 55 percent of the gross value of the global food supply is still produced under rainfed conditions on more than 70 percent of the world’s harvested cropland (Woolley, Cook and Molden, 2009). It is thought that more than half of the world’s rural poor live in low-potential areas, mainly in Asia (Leonard, 2009 in Ashley and Maxwell, 2001), and the proportion who become functionally landless is expected to grow. On-farm storage and management of water supporting diversification have emerged as one part of such a strategy (Woolley, Cook and Molden, 2009), but for the landless, improved access to rainfed common poor resources that are currently under-utilized presents a major opportunity⁴. The incorporation of aquaculture within watershed approaches to development may require a focus on developing capacity for social adaptive learning, market development and/or cash transfers, depending on the context.

⁴ Presentation by G. Haylor and S.D. Tripathi on *Contemporary aquaculture policy and practice in rural India reassessed from the perspective of social inclusion* presented at the National Workshop on Social Inclusion in Rural Development, 9 July, 2008, Bhubaneswar, Orissa.

The well-being of smallholders, in spite of livelihood diversification that includes or may be dominated by off-farm employment is, in the words of Enfors and Gordon (2008), “often intimately linked with local agro-ecological productivity which is largely constrained by water availability”. Ponds, of which one use may be fish production, are “water system technologies” that might have value in escaping dry-land poverty traps. A critical part of how households that incorporate aquaculture within mixed and largely rainfed farming systems enhance their overall well-being appears to be highly related to seasonal benefits to subsistence and/or through small cash benefits during “hungry gaps”. A range of studies in the last decade that have evaluated aquaculture on a “stand alone” basis suggest it makes little economic sense and does not explain adoption or retention, but even relatively small ponds and associated waterbodies can become part of a coping mechanism to avoid nutritional distress, conserve meager cash resources at critical times and maintain social relationships. As such, they may be playing an important part in preventing vulnerable farming households falling into poverty (see comments relating to Krishna earlier) by increasing their overall resilience.

In tandem, the costs of initiating and maintaining aquaculture as a minor strategy on farm have also fallen. Opportunities to obtain required inputs, knowledge, cost of seed and nutritional inputs, together with a decline in the real costs of pond construction have occurred particularly in areas where economies have been growing.

The importance and impacts of local market development to support both “quasi-peasant” and “quasi-capitalist” aquaculture are clear from case studies from both Asia and Africa, as is their coexistence. The importance of aspiration towards “subsistence” in fish production at a household or even community level where continued availability of a variety of species, including indigenous varieties, retains a strong cultural and increasingly, cash value are motives for aquaculture to be retained and further developed as a minor household enterprise (Rossiligni, 2008). The emergence of systems combining aspects of both fish culture and capture mirrors trends to part-time farming and extensification of rice production in some parts of Asia as the urban-based component of many livelihoods strengthen. However, for all the benefits of smallholder aquaculture, the evidence suggests that the most resource-poor people, when adopting secure off-farm employment as the mainstay of their livelihood, benefit only incrementally through direct production. Experience suggests that the provision of subsidies of various types do not appear to change this situation.

Strategies moving forward

A major lesson from the last decade has been improved data to support the hypothesis that commercially oriented “quasi-capitalist” aquaculture can radically change livelihoods of the poor, mainly through generation of employment opportunities through the value chain. The benefits from “quasi-peasant”

aquaculture to the poor are more context dependent and in general of a secondary and incremental nature. Rapid spread of this form of farm diversification among even poor farmers suggests that it enhances well-being on a number of levels. There are clearly a number of policy measures that can support one or both of these types of aquaculture. Tenure to use of land and water may be critical. Efforts to promote aquaculture in the Philippines, Viet Nam and Egypt included the issue of long land leases to provide security to investors and reassurance to lenders. In the Philippines, fish ponds were granted long leases and once developed, lands were titled and transferable and exempted from the comprehensive agrarian reform programme designed to redistribute land (Hishamunda *et al.* 2009; Stevenson and Irz, 2009). Such policies could easily have unintended consequences, however; original grants of 400 ha, later reduced to 250 ha for corporations and 50 ha to individuals, resulted in lop-sided distribution towards large farms and speculative holdings and also encouraged extensification and mangrove destruction. Viet Nam has promoted aquaculture through making it an obligation on local authorities to grant 20–50 year leases and within 90 days of applications being submitted.

Targeting

There is still a widespread assumption by some that aquaculture can and will benefit the poor wherever it is promoted, and that its impacts are always positive. Others believe that any benefits have been vastly overplayed and that aquaculture remains a bastion of the wealthy and often undermines both social and environmental resilience.

A major question in contexts where its role in the mitigation of poverty has been demonstrated remains, what are the most cost-effective means to achieve this objective? For all its potential pitfalls, targeting is clearly a requirement given the heterogeneity of low and medium income countries and the nature of poverty and vulnerability that occurs among their people.

Most efforts over the last decade, and indeed prior to this, have in some way attempted to build adaptive capacity among the poor, typically poor producers, through advocacy, training and local institutional strengthening. Given the primary roles of the poor as intermediaries in value chains and as employees, a major focus should be training and other forms of support for poor actors within value chains who are non-producers. The costs of specialization required of outsiders (whether government, NGO or commercial knowledge brokers) mean that the focus should be on building capacity within the targeted stakeholder groups and, in parallel, a broad level of dissemination of any critical new technical or market knowledge through low-cost approaches that the poor can access locally. Advances in, and reduced costs of, communication technology should support exchange or practical-based visits to successful but otherwise similar contexts. In areas where commercial aquaculture has gained a significant presence, the cost of delivering such support should be shared through public-private

initiatives. Tripp (2001) suggested that new agricultural technology development remains critical for lifting people out of poverty, although arguably appropriate generic technologies exist for aquaculture, and constraints relating to adoption of aquaculture by the poor are more likely to be social and institutional. Certainly support strategies are likely to be very different for the emerging class of commercial farmers, many engaged with global commodity chains, who need support in managing information and skill-intensive knowledge in contrast to the needs of a semisubsistence often part-time farming class.

New thinking has emerged over the last decade as to how this can be best and most cost-effectively implemented. The concept of producer clubs, such as has been promoted in India by the Network of Aquaculture Centres in Asia-Pacific/Marine Export Promotion and Development Authority (NACA/MPEDA) among small shrimp producers to upgrade their systems and market their products (Umesh *et al.*, 2010), is an example of adaptive management in practice and an approach to social and environmental resilience. Detailed analyses on impacts on poverty, both among the producers and wider networks are urgently required, as are lessons learnt on the effective governance of such institutions in India and similar developments elsewhere (Little, 2010).

The role and sustainability of private and non-formal sector approaches to delivering information and services through information and trading nodes (one stop aqua shops, OSAS) also requires more widespread piloting and development. Initiated in eastern India and Bangladesh as project-based initiatives, they have recently been piloted in East Africa (SARNISSA, 2010). In Uganda, technical support to fish farmers is now provided by private-sector consultants, facilitated by the dissemination of public-sector agricultural support funds to farmer organizations.

Opportunities for aquaculture interventions in common-pool resource contexts are likely to persist in LDCs. The shared characteristics of such resources underpin claims for increased potential for inclusion of the poor, especially the functionally landless. However, despite such seemingly democratic credentials, aquaculture development has a poor track record in these systems. Failure is often attributed to associated physical constraints, including the inherent unpredictability of production parameters in semiclosed systems. However, institutional failures are a major contributory and arguably underlying cause for many examples of unsustainable “sunset” development. Indeed, there are many examples of poorly considered interventions creating or igniting latent resource conflicts. These failures operate at the non-governmental and governmental levels, as illustrated by case studies from Sri Lanka (Murray, 2006). Traditional village settlements in rainfed lowlands occur around seasonal reservoirs used for a range of functions. Development interventions typically focus on the primacy of one or more productive-functions, ignoring a wide range of alternative functions: symbolic, religious, social, etc., with a mix of competing

and synergistic interactions. Furthermore, interactions occur at much wider levels beyond the immediate resource boundary, both physically and socially. Such relations are the focus of watershed development models elsewhere but have seen little effective integration of aquaculture.

Current impacts on the poor are strongly related to benefits through employment which are magnified by the fragmented and complex nature of value chains; these provide a multitude of niche opportunities partly through technical “inefficiencies” that include the “leakage” of systems through stock losses and postharvest gleaning. In the interim, these provide opportunities for safety valves for the poor, but population trends suggest that rural areas will potentially become holding grounds for the very young and old as a majority of working-age adults migrate to industrial and urban areas for better paying off-farm livelihood opportunities (Ashley and Maxwell, 2001). This will have implications for employment and labour efficiency. Also, as relative increases in functional landlessness are likely, most farms will become commercial, larger and more closely integrated with respect to inputs and outputs, logically resulting in less “niches” currently filled by poor actors. Rural livelihoods will increasingly become more non-agricultural in origin, but often linked to agriculture. This is amply demonstrated in areas of commercial aquaculture for which employment in ancillary services has grown rapidly and investments made to support further employment growth in these areas.

Better methodological approaches are required to understand the impacts of aquaculture on poverty that seek to clarify negative outcomes on stakeholders who are not producers or even involved directly in the value chain. A key necessity is a better understanding of the variability and dynamics of the physical and human systems that define aquaculture through a well-defined and adequate sampling frame.

Matching the agricultural agenda for transforming countries (World Development Report 2008) – an aquaculture agenda.

The World Development Report 2008 (WDR) (World Bank, 2007) identified seven themes in a development agenda for transforming countries (Table 3) around which this review is summarized.

Arguably the “blue revolution” has occurred on many fronts in the last few decades and is not characterized by a series of narrow technocentric developments in germplasm development and chemistry such as launched the green revolution several decades earlier. The role of urban income drivers within transforming countries in kick-starting aquaculture development are clear, as indicated by many of the examples given above. The global trade in aquaculture products has been largely initiated through smallholder production, but such producers face many challenges and significant consolidation has occurred. Survival of smaller producers will require both institutional and technical innovation to

TABLE 3
Themes to the agenda for transforming countries

	Theme	Notes
1	Green revolution to new agriculture	Rapid growth of urban incomes and demand for high-value products are the major drivers for faster agricultural growth and poverty reduction in transforming countries, although sustainable productivity growth in food staples requires continued attention. Because there are scale economies in processing and marketing of many high-value products, institutional innovations such as contract farming can reduce the transaction costs and risks to smallholders. Linking smallholders to processors and retailers can also create access to more financial capital through banks – and provide technology, extension and buyback arrangements, while monitoring food safety. A high priority is to improve the investment climate for agribusiness and facilitate collective action through producer organizations to reach scale in marketing and to bargain for better prices. Reform of price and subsidy support to cereals will also be needed in many cases to provide the incentives to diversify to high-value products.
2	Dealing with water scarcity	Reforming institutions in irrigation, removing policy distortions such as water and electricity subsidies, and providing a supportive environment for trade and macroeconomic policies are all important steps in improving water productivity and meeting competing demands. Broad-based reforms require strong champions and equitable allocation of water rights to overcome the political obstacles. As scarcity worsens, water markets may come into play, with support needed for their emergence and eventual regulation.
3	Making intensive systems more sustainable	Reducing the environmental footprint of intensive agricultural systems, especially agrochemical and animal waste pollution, is a priority for improved environmental and human health. It will also reduce the drag on productivity growth from land and water degradation. More sustainable agricultural practices will require a judicious combination of getting incentives right (through input and output prices), application of improved management technologies such as integrated pest and nutrient management, and better regulation.
4	Development of lagging areas	With the shift to the new agriculture and the declining farm size in high-potential areas, increasing farm productivity and incomes in less-favoured regions can secure the livelihoods of subsistence farmers and bring them to the market. Productivity growth in these regions rests on major investments in soil and water management, in agricultural research and in new approaches to extension, supported by reforms in pricing and marketing for grains.
5	Rural development off the farm linked to towns	Growth in rural non-farm employment in many cases remains closely linked to growth in agriculture, as agriculture is the main supplier of intermediate inputs to other sectors such as processed foods (forward links). Regional and territorial development of agricultural clusters – with the processing and packaging of high-value products – is an opportunity for rural non-farm development. In densely populated countries, urban-based industries will drive the rural non-farm sector through urban-to-rural subcontracting. Investments in infrastructure and skills and improvements in the investment climate for the private sector are the policy priorities. Developing land market to enable small farms to consolidate for efficient operation and to shift labour to non-farm activities and migration is also a priority.
6	Skills for successful migration	Successfully moving out of agriculture, whether by moving to the rural non-farm sector or by migrating to urban areas, depends on more and better quality education. Massive investments in human capital are needed to prepare the next generation to leave agriculture. Programmes that provide conditional transfers, such as cash grants in Bangladesh conditioned on school attendance, can increase the demand for education, but they will fail unless the quality of rural education is greatly improved.
7	Safety nets for those left behind	Transforming countries have the largest concentration of the world's poor, so direct support through well-designed and well-governed employment schemes in rural areas – including rural infrastructure, reforestation, soil conservation structures, small dams and desilting of canals and ponds – can reduce poverty, improve the rural investment climate and restore degraded natural resources. Significant monitoring, accountability mechanisms and rigorous evaluations are needed to ensure effective and equitable resource use.

Source: World Bank (2007).

reduce transaction costs and risks through better linking to, and greater equity within, value chains.

Overcoming water scarcity is a key linkage between aquaculture and broader agriculture, since some forms of the former are profligate users of water and a major issue is the extent to which they are consumers. IAAS have been promoted mainly on a small scale as part of diversified smallholder food production systems, but similar thinking now needs to be applied at all scales of production. Intensification of aquaculture has implications for efficiency of water use, both direct and indirect, through use of more feeds requiring irrigation for their production. Approaches to aquaculture promoted for poorer people such as integrated rice-fish systems will also need to consider water efficiency as a key parameter as water regulation and costs increase.

A major and continuing developmental trend is the intensification of aquaculture. A key element in making intensive aquaculture systems more sustainable is the reduction of adverse environmental impacts, both proximate and global, and this requires more interdisciplinary approaches to R&D. Measures taken to ensure greater sustainability are also likely to support further growth in global trade. The widespread and increasing use of formulated diets is expected to further expand, even as aquaculture in extensive forms becomes better integrated into overall water resource use.

Aquaculture, even when “inefficient” in stand-alone terms, can be an important component to approaches aiming to enhance well-being in marginal agro-ecosystems “lagging” in development, and relatively greater attention should be shifted to the governance and use of the numerous and often under-utilized rainfed waterbodies.

The huge growth in commercially oriented quasi-capitalist and capitalist aquaculture, typically in location-specific contexts, particularly in Asia, indicates the benefits for addressing rural poverty of improved linkages and often, migration, to urban areas. The rise in importance of the development of rural non-farm value chains, both for input supply and processing, has been documented. Skilled migrants have been important to the transfer and adoption of aquaculture in many parts of the world. Much of the aquaculture now present in Southeast Asia, for example, originated through Chinese immigrants and their descendants (Edwards, 2004), and movement of ideas and products continues to energize and advance the sector. The mobility of a variety of “actors”, from poor seed traders to employees of transnational corporations (e.g. Goss, Burch and Rickson, 2000) implementing turnkey projects, is a continuing and critical part of this story.

Transforming countries have the largest number of poor people most dependent on fish for their nutritional security. The further development of urban-rural

linkages is critical to the safety net that aquaculture development can support. In addition to remittance income, where appropriate, the further development of water storage infrastructure and institutional changes that allow access to water resources for the rural poor for subsistence and income generation are warranted. Support for adaptive change towards efficient and equitable resource use should be at the centre of these efforts. A summary of poverty issues in relation to development of aquaculture s given in Table 5.

Relations of production	Characteristics					
	Quasi-peasant		Quasi-capitalist		Capitalist	
Production intensity	Low	Low or moderate	Moderate	Moderate or intensive	Moderate or intensive	Highly intensive
Capital & operating costs	Limited	Moderate	Substantial	Substantial	High	Very high
Ownership & labour	Family owned & operated	Family owned & operated	Family owned & operated	Family owned & operated or absentee owner Part-time &/ or permanent labour	Family owned & operated or absentee owner Permanent labour Managerial staff	Absentee owner or corporate ownership Permanent labour Professionalized managerial, technical & clerical staff

TABLE 5
Summary of poverty issues in relation to development of aquaculture

	Poverty issues	Positive	Negative
1	Low and erratic income flows	Involvement in aquaculture value chains can increase seasonal or year-round income generation, either through ownership or leasing of production facilities or through employment. Intermittent harvest and trading of fish can smooth income flows and consumption demand. Short-cycle systems such as aquatic vegetables and juvenile production tend to particularly good cash flow.	Income flows from small household managed systems are often marginal, and the risks of loss (e.g. flooding, theft) predicated against further investment.
2	Low and erratic food availability	Increased levels of aquatic farming increase abundance and availability of products for consumption and/or purchase. May supply food during hungry gaps, particularly in marginal agro-ecosystems.	Resources used for aquaculture (e.g. “trash” fish, fishmeal/oil) may have direct human consumption value for the poor or result in inputs being diverted away from traditional uses (e.g. brans, oilcakes, etc.), with negative impacts on livelihoods of the poor.
3	High opportunity costs of land/water	Opportunities for rental income for those with land/water.	Poorer people lose access to resources year-round, seasonally or periodically.
4	Landlessness	Rise of a market in leased ponds may allow opportunities for landless people to participate. Landlessness does not constrain access to other employment opportunities in the value chain, i.e trading of inputs and products, processing. Cage farming can be practiced by land-poor households.	Landlessness and poor access to other assets may constrain opportunities for direct involvement in culture. Landless people may not have the other resources and capacities to support high-input cage systems.
5	Price of aquatic products in markets	Aquaculture development can lead to stabilization or even declines in the real price of aquatic foods, which is good for poor consumers.	Price declines can also reduce margins for farmers and others in the value chain
6	Nutritional quality of aquatic products	Farming can allow manipulation of the nutritional quality of fish and other aquatic products. Potential environmental contaminants affecting unmanaged stocks in open waters can be controlled or avoided.	Pressures to decrease production costs can stimulate the use of poorer quality feed ingredients and/or inputs that may negatively impact on human health (e.g. antibiotic residues, etc). Difficulty in controlling contaminants from the external environment.
7	Lack of knowledge	Households learning about fish culture and/or other aspects of the value chain that may enrich other aspects of life and potential employment.	Lack of knowledge may constrain uptake and adoption of activities within aquaculture value chains.

TABLE 5 (Continued)

	Poverty issues	Positive	Negative
8	Intergenerational food and income security	Evidence for poorer households, even those with small culture systems, consuming more fish and, if integrated, also have improved access to meat, eggs and vegetables. Adoption of aquaculture may lead to the returns being preferentially invested in children's education.	Intrahousehold access to, and consumption of, fish and other related cultured products may not reflect greatest needs of household members.
9	Enhancing well-being	Benefits from adoption of aquaculture are often numerous and relatively minor when considered individually but taken together meet many social, consumption and other felt needs.	
10	Difficulty in targeting poor groups	Interventions have been successfully targeted to groups most at need, including those involved as service operators in value chains	Danger of creating conflicts and competition among poor people and between the poor and the better off, exacerbating tensions. Ignorance of stakeholders who can "lose out" through aquaculture development.
11	Elite capture of benefits of aquaculture	See 10. Sustaining benefits among poorer groups typically requires culturally sensitive institutional change, capacity building and ongoing support. Even in contexts where elite capture has occurred, the range of employment niches generated can be positive to poorer people.	Aquaculture can support elite capture of common-pool resources and lead to gross inequities within value chains.
12	Risk and resilience of farming aquatic products	Household ponds and diked embankments, particularly those that can store water year-round, can support socio-ecological resilience for both producer households and other community members through maintaining consumption and income flows (see 1, 2) and offer protection against both drought and flood and associated crop productivity and survival. Institutional development among members of aquaculture value chains (e.g. producer groups) may be critical to longer-term risk management strategies, especially those exposed through use of high input, open culture systems dependent on global markets.	Aquaculture, particularly high input, intensive systems, can be highly risky, potentially exposing producers and others in the value chain to risk. Dependence on external markets for inputs and products intensifies such risks.
13	Ponds as multipurpose resources, especially on-farm water storage	Ponds that support multicommodity food production are likely to enhance resilience (see 12). Polycultures within ponds and the use of ponds both as a location and source of water for irrigation of surrounding crops are key features that can enhance benefits and mitigate production or market failure. The value of aquaculture systems as nutrient sinks that can be exploited by surrounding agriculture is typically under-optimized.	Multiple outputs from IAA often demand more complex management and access to resources that are not compatible with poor livelihoods dependent on off-farm employment. Sustained, commercially oriented IAA typically require significant access to knowledge and inputs.

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Sustaining aquaculture by developing human capacity and enhancing opportunities for women

Expert Panel Review 6.3

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Abstract

People are at the heart of sustaining aquaculture. Development of human capacity and gender, therefore, is an important human dimension. Human capacity development (HCD) was a major thrust of the 2000 Bangkok Declaration and Strategy, but gender was not addressed. The Food and Agriculture Organization of the United Nations (FAO) Strategic Framework for Human Capacity Development (HCD) emphasized building human capacity in a coherent fashion at four levels – in individuals, organizations, sectors/networks and in the overall enabling environment. Although strategic HCD in aquaculture has not received attention, substantial HCD has occurred in aquaculture education and training. Aquaculture departments in universities, aquaculture research institutes, networks and professional societies all include training as central activities.

Women are active participants in aquaculture supply chains, but a dearth of gender-disaggregated information hampers accurate understanding of their contribution. Research results and FAO National Aquaculture Sector Overview (NASO) fact sheets show that female participation rates vary by type and scale of enterprise and country. Women are frequently active in hatcheries and dominate fish processing plant labourers. Women's work in small-scale aquaculture frequently is unrecognized, under or unpaid. Most aquaculture development projects are not gender sensitive, and aquaculture success stories often do not report gender dimensions; projects can fail if their designs do not include gender.

Lacking gender-disaggregated data on participation rates and trends in education, we conducted a preliminary survey of aquaculture tertiary institutes in Africa, Asia, Europe and North America. The percentage of female graduates in aquaculture increased considerably over the last four decades, from zero or low numbers in the 1970s to recent rates of around 30–60 percent; rates vary both by country and within countries. No data are available to track whether female graduates are entering successful careers in aquaculture.

To accelerate HCD to meet the needs of aquaculture growth, commodity and theme priorities for HCD must be established. Educational institutions should cooperate and harmonize work programmes and overcome language barriers. Aquaculture education needs the best students and should help prepare them for rewarding careers. More social science content is needed in aquaculture curricula to groom graduates for management and leadership roles. The gender balance in aquaculture faculty could be improved by recruiting and retaining more women.

Gender should be put firmly on the policy agenda and built into normative instruments, old and new, complemented by the collection of gender-disaggregated data for aquaculture supply chains. Women should be empowered through gender equity in access to financial, natural, training and market resources.

Women in aquaculture should not be stereotyped as “small-scale” and poor. Women are often hampered by systemic barriers such as lack of legal rights. Women should be encouraged to build their management, leadership and entrepreneurial skills. In circumstances where rural men have migrated for work, small-scale aquaculture has proven a suitable livelihood option to reduce the pressure on women. Because postharvest processing and fish trade are feminized occupations, gender equity deserves special attention in fair trade and fish certification schemes. HCD and gender are receiving more attention in rehabilitation efforts to assist survivors from disease and natural disasters.

KEY WORDS: *Aquaculture, Gender, Human capacity development.*

Introduction

People are at the heart of sustaining aquaculture. Human capacity and gender, each in its own right and in combination, are important human dimensions. For human capacity development (HCD), gender is an issue; women and men both need education and training on aquaculture to provide them with the knowledge to contribute to greater national and household food supply, security and income. A key message from the Food and Agriculture Organization of the United Nations’ report *The State of Food and Agriculture 2010–11. Women in Agriculture – Closing the Gender Gap for Development* (FAO, 2011) was that women’s relative lack of access to education and extension services contributed to the “gender gap” in agriculture (including aquaculture) productivity.

HCD is a cross-cutting issue. In the 2000 Bangkok Declaration and Strategy (NACA/FAO 2000), Key Element 3.1 *Investing in people through education and training* recommended five action points to build the knowledge, skills and attitude of people involved in the sector. Capacity building, both institutional and human, was also highlighted in other key elements of the Bangkok Declaration (e.g. 3.3. *Improving information flow and communication*, 3.8 *Strengthening institutional support* and 3.11 *Managing aquatic animal health*). In this paper, we review progress in implementing the Bangkok Strategy and recommend a more comprehensive approach to give HCD in aquaculture new impetus. The FAO’s Strategic Framework on Human Capacity Development in Fisheries (FAO, 2005) was used for its definition of HCD and as a key entry point.

The 2000 Bangkok Declaration did not include gender elements, and thus we proposed new gender strategies to the 2010 Global Conference on Aquaculture (GCA). We addressed gender throughout fish supply chains. We also addressed the goal of creating a productive and fair sector through gender-equitable practices and policies, using global terms as defined by FAO and other United Nations agencies.

Definitions for some key HCD and gender terms are presented in Box 1.

BOX 1. Some Key HCD and gender terms.

Human capacity development – the process by which individuals, groups, organizations, institutions, and societies develop their abilities, both individually and collectively, to set and achieve objectives, perform functions, solve problems and to develop the means and conditions required to enable this process (FAO, 2005).

Gender – the qualitative and interdependent character of women's and men's position in society (FAO Aquaculture glossary, www.fao.org/fi/glossary/aquaculture/default.asp). Gender roles vary across time, place and region according to changing values, practices and technologies. Gender roles and responsibilities are largely socially constructed and are the basis for the structure and organization of women's and men's differential relationships with their environments, the economy, their resource utilization patterns and strategies (Williams, Hochet-Kinbongui and Nauen, 2005).

Gender relations – the relations of power and dominance that structure the life chances of women and men (www.fao.org/fi/glossary/aquaculture/default.asp).

Gender equality – equality between men and women. Gender equality entails the concept that all human beings, both men and women, are free to develop their personal abilities and make choices without the limitations set by stereotypes, rigid gender roles and prejudices. Gender equality means that the different behaviour, aspirations and needs of women and men are considered, valued and favoured equally. It does not mean that women and men have to become the same, but that their rights, responsibilities and opportunities will not depend on whether they are born male or female. Gender equity means fairness of treatment for women and men, according to their respective needs. This may include equal treatment or treatment that is different but which is considered equivalent in terms of rights, benefits, obligations and opportunities (ILO, 2000).

Knowledge, practice and trends in the 2000s

Human capacity development

In the early years of the last decade, fisheries and aquaculture HCD was addressed by the Asia-Pacific Expert Consultation on Aquaculture Education (De Silva, Sim and Phillips, 2000) and the 2002 meeting of the FAO Advisory Committee on Fisheries Research (ACFR) that identified “Building human capacity” as a “mega priority cross-cutting issue” (FAO, 2003). The latter recommended that the FAO Fisheries Department (now the Fisheries and Aquaculture Department) should address capacity building with a more strategic approach to complement its valuable ongoing work. FAO subsequently commissioned work that led the ACFR, in 2004, to approve the Strategic Framework on Human Capacity Development (FAO, 2004, 2005). However, although many individual HCD activities were conducted, no concerted global programme or strategy was eventuated. HCD was not on the agenda of the FAO Committee on Fisheries and Aquaculture (COFI). Complacency by aquaculture policy-makers may have been partly because aquaculture production continued to expand despite the lack of attention to HCD strategies.

The FAO strategic framework still remains relevant. One of its key features was to emphasize that human capacity needs to be built at four levels (see Figure 1),

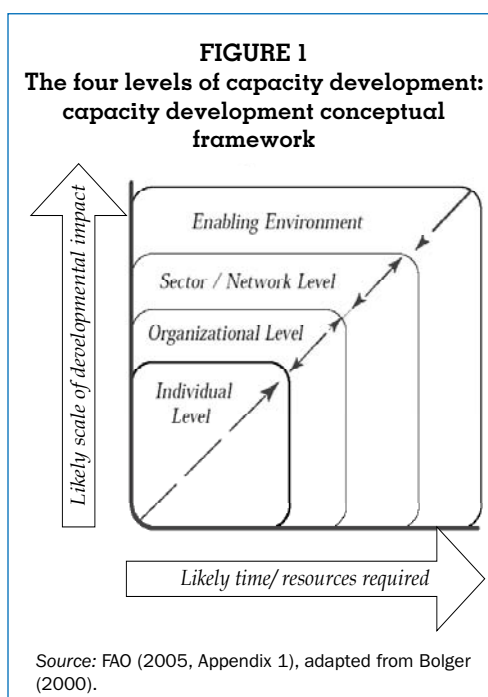
namely in individuals, organizations/institutions, sectors and networks, and the overall enabling environment. For aquaculture, the levels of the scheme can be interpreted as follows:

- The *individual* could be a student, trainee, farmer, worker or official whose capacity is being specifically developed through training, education or some less formal process.
- Depending on who is the individual, the *organization* (or institution) could be the household, farm, factory, employing firm, government agency, university or research institute within which the individual does or will undertake aquaculture-related activities.
- The *sector/network* could be the commodity production system or specialist thematic field (e.g. fish disease diagnostics) within which the individual and her/his organization operates.
- The *enabling environment* could be the society, policy, laws, markets, environment and their combinations that create the operational support and regulatory systems within which the three above levels operate.

For an HCD strategy to succeed, action must be aligned across the levels. This bottom-to-top coherence from individuals to purpose and environment was illustrated in CARE Bangladesh's Agriculture and Natural Resources Programme when the organization realized that it could not achieve all the benefits it wished for women unless the CARE Bangladesh organization had appropriate internal HCD, staffing and attitudes (Debashish *et al.*, 2001). Gender equity had to be established first at the level of individuals, e.g. by employing female staff, and inside the organization, by the way staff were treated and behaved.

The FAO strategic framework also recommended integrating efforts for three knowledge and skill areas that, applied to aquaculture, would be: (i) aquaculture science and research, (ii) aquaculture sector management, and (iii) societal skills and knowledge focused on aquaculture-specific issues. All are still highly relevant.

Although global attention to HCD was lacking, some regions and most countries did progress aquaculture capacity development, especially in tertiary education.



For example, European countries and the European Union (EU) supported the AQUA-TNET (EU Thematic Network for Aquaculture, Fisheries and Aquatic Resources Management); China, India and many other Asian countries upgraded their aquaculture education programmes, creating many new postgraduate programmes, more comprehensive undergraduate programmes and broadening the scope of tertiary aquaculture education to meet social as well as industry needs (ISAFE, 2009). Capacity building also remained a vital part of the work programmes of international specialist institutes such as the Network of Aquaculture Centres in Asia-Pacific (NACA), the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) and The WorldFish Center.

Recognizing the rapid development of aquaculture, many universities and other tertiary education institutes that had not previously taught aquaculture have been attracted into offering aquaculture courses, as well as bachelor's degree and post-graduate courses. Many higher education institutes have switched most of their courses from fisheries to aquaculture or at least shifted the balance of courses to favour aquaculture. Scholarships and sponsorships in aquaculture have aided this shift.

Gender

Although reliable estimates are not available, women probably are more involved in aquaculture than in the fisheries sector (Weeratunge and Snyder, 2009). Despite this, women/gender studies are more numerous for fisheries than for aquaculture. In an FAO bibliography covering gender and fisheries/aquaculture reports published between 1990 and 2001 (Kyprianou, 2001), fewer than 10 percent of the reports were on aquaculture. More recently, between 1998 and 2007, in the four triennial symposia on women/gender in fisheries conducted by the Asian Fisheries Society (AFS), fewer than 25 percent of the papers were chiefly focused on aquaculture, more than half focused mainly on fisheries and the remainder were equally focused on aquaculture and fisheries.¹ Women in fisheries publications such as those of the Secretariat for the Pacific Community Women in Fisheries Information Bulletin (<http://www.spc.int/coastfish/en/publications/bulletins/women-in-fisheries.html>) and Yemaya published by the International Collective in Support of Fishworkers (ICSF) (<http://wif.icsf.net/icsf2006/jspFiles/wif/index.jsp>) mainly focus on fisheries. The lesser attention to gender in aquaculture versus fisheries may be due to the more recent history of aquaculture and academic interest in the complex sociology and anthropology of fishing communities and practices.

Over the last ten years, gender issues in aquaculture received little global attention. The period started promisingly with several key studies, such as

¹ Based on analysis of the published original papers in Williams *et al.* (2001, 2002), Choo, Hall and Williams (2006) and, as only selected papers were published, from the programme of the 2007 symposium (<http://groups.google.com/group/GAF2>).

those in the Asia Pacific Economic Cooperation (APEC) project led by the Asian Institute of Technology (AIT) and University of Stirling (Brugere *et al.*, 1999; AIT, 2000; Kelkar, 2001; Kusakabe and Kelkar 2001; Kusakabe, 2003). Subsequently, research became more dispersed and much was carried out in separate projects.

FAO has not addressed gender and aquaculture in a comprehensive way since 1987 (Nash, Engle and Crosetti, 1987), although many local and regional activities have been undertaken (e.g. Nandeesh, 2007) and FAO National Aquaculture Sector Overview (NASO) fact sheets (www.fao.org/fishery/naso/search/en) (Table 1) show that women and children, as well as men make important contributions. In addition, towards the end of the last decade, the lessons learned from aquaculture (and fisheries) studies were codified under the theme “Gender in Fisheries and Aquaculture” in the *Gender in Agriculture Sourcebook* (World Bank, FAO and IFAD, 2008) and in FAO (2007). Under social capital, women’s involvement in major decision-making roles in small-scale aquaculture has been identified as one of 14 indicators for assessing the contribution of small-scale aquaculture to sustainable rural development (Bondad-Reantaso *et al.*, 2009).

The FAO report, *State of World Aquaculture 2006* (FAO, 2006) collated available information on employment in aquaculture, where possible disaggregated by gender. Unfortunately, data for Asian countries, the dominant aquaculture region, were largely lacking. In Africa, FAO reported that women own or manage 16 percent of farms and play only a minor role in fish production, although they make large but unquantifiable contributions in fish processing and marketing. Women’s roles in managing aquaculture production differ greatly depending on commodity and country. For example, in Madagascar, Mozambique and Tanzania, women own and/or manage more than 80 percent of the seaweed farms. In South America, women’s participation in aquaculture, except in processing plants and subsistence aquaculture, is estimated at only 5 percent of workers. Across most Eastern European countries, women’s fish farming participation is as low as 5–10 percent, but rises to 20 percent in Ukraine, 50 percent in Estonia and up to 70 percent for some fish breeding farms in Russia. In 2004, in Canada, the female workforce was about 28 percent.

Despite its limitations, available information indicates that aquaculture labour, roles and responsibilities are not gender-determined but that a considerable degree of gender differentiation occurs in practice, conditioned by many social, economic and personal factors. The roles also depend on the type of aquaculture. For example, in some countries such as Mexico, in intensive or semi intensive commercial aquaculture, professional female and male staff perform the same kind of activities, whereas, in sub-Saharan Africa, rural people with low educational levels tend to assign traditional roles to women. Thus, gender roles and contributions need to be understood within their context and characterized

with respect to economic, social and individual assets and people's needs. Characterization may present special methodological challenges, especially if the contribution is made by unpaid and/or unrecognized labour. A further challenge comes from the rapid development of aquaculture that is accompanied by rapid changes in supply chains and hence in labour, roles and contributions.

Educational level is a particularly potent determinant of who does what and therefore, the contribution made. Compared to illiterate women, those with schooling tend to be more active in small-scale operations such as wild fry collection, hatchery and fish nursery phases, feeding and other husbandry tasks, postharvest processing and marketing and can even dominate these stages of the supply chains. For example, women high school graduates dominate factory floor jobs in export prawn processing plants in Sri Lanka because they can comprehend the quality control procedures (De Silva and Yamao, 2006). However, although education can give women access to a greater range of aquaculture activities, their control over resources and decision making is not only linked to their knowledge and know-how but is also affected by household, community, social and economic settings. Men tend to be responsible for pond and cage construction and maintenance, stocking and harvesting (e.g. see Kibria and Mowla (2006) for an example of labour division).

Despite their participation, many women receive low economic returns from aquaculture and experience poor working and social conditions. Yet, women and poverty should not be conflated in aquaculture development, or indeed in development more generally (Jackson, 1996). Some women do or could populate the more entrepreneurial segments of the supply chains, particularly in value-addition jobs and marketing in East and Southeast Asia. Much of the discrimination that may constrain women's aquaculture progress is driven by other factors such as legal rights to assets and cultural mores and is not due to poverty.

Despite many development organizations having gender policies and strategic plans to mainstream gender, most aquaculture projects and programmes are not gender sensitive. For example, a review of five projects in one fisheries development programme in Bangladesh showed that women's roles were minor or largely overlooked, including in the four aquaculture projects (Halim and Ahmed, 2006). Where the Bangladeshi women worked in the aquaculture enterprises, their work contributed to the household finances but did not necessarily give them more decision-making power. Gender is overlooked in developing many pond/fish farming activities and is rarely addressed in education and training.

Development projects also rarely address whether the benefits of aquaculture are really obtained by women and children. Although women may generate income through aquaculture, this may be at the expense of increasing their overall workloads.

TABLE 1
Examples of women’s involvement in the aquaculture workforce from the FAO National Aquaculture Sector Overview (NASO) Fact Sheets

ASIA	
Bangladesh	Motivated by women’s non-governmental organizations (NGOs) and other entrepreneurs, women have been encouraged to participate in aquaculture activities.
China	Women’s participation is higher in small-scale and family-run aquaculture systems than in other enterprises.
Japan	In 2003, there were 23 068 enterprises engaged in marine aquaculture, employing 69 645 workers in the high season, of whom 51 percent were women. About 4 495 enterprises were engaged in freshwater aquaculture, employing 11 558 people, of whom 31 percent were women. However, the number of enterprises and workers has been declining in recent years.
Malaysia	Women, who account for about 10 percent of the total aquaculture workforce, are mostly involved in freshwater aquaculture, particularly cement tank culture and hatchery operations for marine fish, shrimp and freshwater fish.
Philippines	Women are an integral part of production and postharvest activities.
Sri Lanka	Five percent of the workforce in shrimp aquaculture are women, whereas 30 percent engaged in the production and breeding of ornamental fish are women.
Thailand	Women participate particularly in activities related to feed preparation, feeding, harvesting, processing, accounting and marketing.
SOUTH AMERICA AND THE CARIBBEAN	
Belize	Most of the workers involved in processing are women from rural communities with high levels of unemployment and poverty.
Cuba	About 27 percent of the aquaculture workforce are female (19 percent are technicians with intermediate and higher education compared to 11 percent of all workers).
Guatemala	Women work mainly in shrimp processing plants.
Guyana	Women are mostly involved in brackishwater aquaculture.
Jamaica	Women own and operate 8–11 percent of the fish farms; in processing plants, women dominate the workforce.
Panama	Women make up 80 percent of the workforce in processing plants but in the production sector, only 7 percent are women.
EUROPE	
Estonia	The gender ratio in the aquaculture workforce is 1:1.
WEST ASIA AND NORTH AFRICA	
Israel	The aquaculture workforce has high skill levels because of the advanced technical nature of Israeli aquaculture. Most, if not all workers, have at least a high school diploma, and a high percentage have a degree (B.Sc. or M.Sc.). Women make up about 95 percent of the workforce.

Source: www.fao.org/fishery/naso/search/en (accessed 25 June 2011).

In aquaculture development, ignoring gender can harm social relationships and undermine the potential for aquaculture progress. In Tabasco, Mexico, men and women were found to have different motivations for aquaculture, and ignoring these led to the introduction of inappropriate technologies and extension methods and the ultimate failure of some projects (Galmiche-Tejeda and Townsend, 2006). Given the range of skills and knowledge needed for such work, most successful examples of incorporating gender, all from small-scale aquaculture, have involved partnerships among different types of complementary

agencies. These linkages aid the effective exchange of information, pooling of skills and lessons on gender issues.

Starting in 1995, the Asian Fisheries Society (AFS) began highlighting the role of women in fisheries, stimulated by initial linkages with the PADEK-Cambodia fish culture programme (Nandeeshha and Tech, 2002). Over the last ten years, further progress in raising awareness has been made (e.g. the 2001, 2004 and 2007 AFS symposia on women/gender and fisheries), plus other efforts (Williams, Hochet-Kinbongui and Nauen, 2005). The AFS, FAO and others continue to highlight gender issues through triennial women/gender symposia (e.g., through the 2011 3rd Global Symposium on Gender in Aquaculture and Fisheries and Website <http://genderaquafish.org/>). In recent years, the World Aquaculture Society (WAS) began holding sessions on women in aquaculture at their annual conferences. The 2005 World Food Prize was awarded to Dr M.V. Gupta for disseminating low-input freshwater fish farming to, among others, poor women and landless farmers.

Despite the growing knowledge and rising awareness on gender, little progress has been achieved in collecting gender-disaggregated statistics and in incorporating gender in aquaculture and fisheries normative instruments. The low participation of women in the more lucrative aquaculture activities, such as carp, salmon and shrimp farming, is often taken by development planners as a sign that there are no gender issues to be addressed, whereas the dearth of women may instead be interpreted as an opportunity for more women to become involved.

The slow progress on gender information is a major constraint to progress on gender issues. When addressing gender issues, gender-disaggregated data and information are essential (Razavi and Miller, 1995) to understand their importance in productive enterprises such as aquaculture or to promote equity and women's rights. Whereas manuals and expert guidance have now been developed for collecting gender-disaggregated information in other rural sectors such as water, household energy and to some extent agriculture, the aquaculture and fisheries sectors have not developed guides to collecting gender-disaggregated information and deriving indicators (Williams, 2010). In science and technology (S&T), some gender-disaggregated statistics relevant to aquaculture are collected by the Agricultural Science and Technology Indicators Programme (<http://www.asti.cgiar.org/gender-capacity>). Beintema and Marcantonio (2010) found that gender-disaggregated data on S&T focus more generally on S&T rather than on agriculture, as a whole, or aquaculture specifically. Also, data are not always comparable across countries because different methodologies and coverage are used.

In the absence of sufficient data, progress towards gender equity and equality in aquaculture is difficult to assess because data are not available. For example,

in a review of successful Asian fisheries aquaculture development (De Silva and Davy, 2009), only two of eight case studies substantively addressed gender issues. Often, studies, such as most of those on aquaculture in the AFS symposia on women/gender, focus mainly on projects with positive gender interventions, rather than studies on current realities.

HCD and gender

Gender-disaggregated participation rates and their trends are not readily available for aquaculture education and training. Hence, we conducted a preliminary survey of institutes to better understand the rates and trends.² Over the last 40 years, female participation moved from negligible to sizeable levels, approaching and occasionally exceeding male rates.

Tertiary education

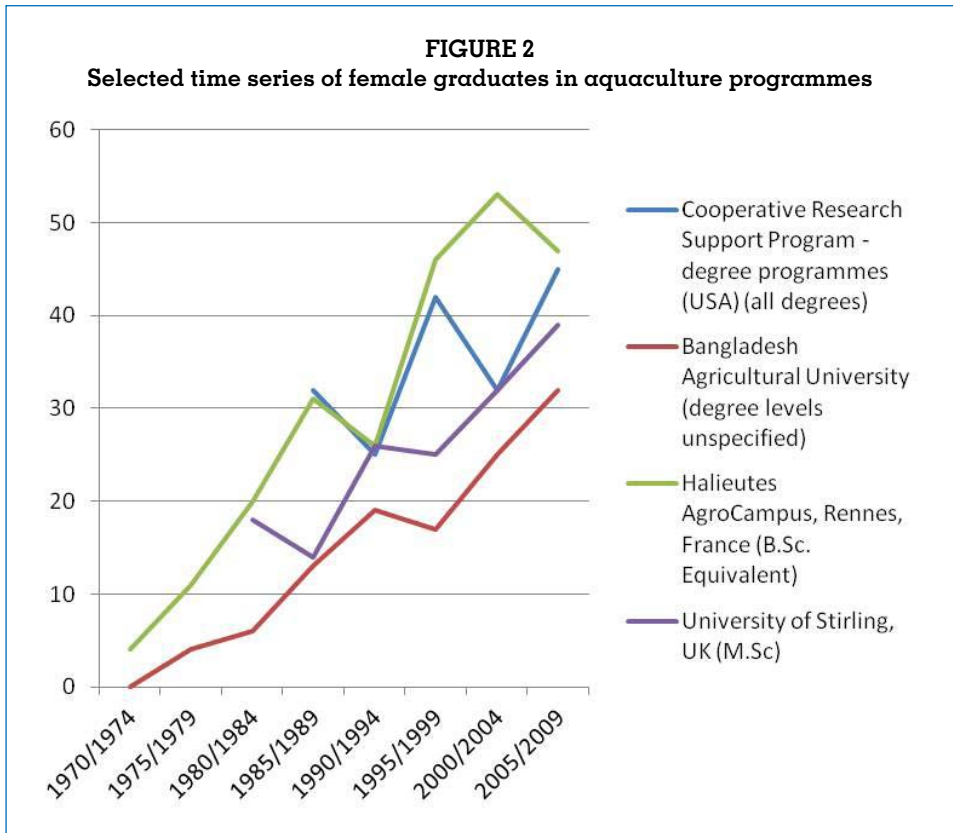
Data were obtained from 18 institutions and programmes, nine from Asia, four from Europe, three from Africa and two from the United States of America. These data were from the larger and more long-term providers of aquaculture specialist education, but we recognized that major gaps exist (e.g. South America, China). The data sets were of varying length and detail, the earliest from 1970 (France) and 1972 (Bangladesh), and therefore, time series comparisons are difficult. Although the statistics refer to aquaculture and fisheries graduates in some universities, in more recent years, the graduates were predominately from aquaculture.

Regional and international degrees and higher education programmes have been important in the early and continuing development of aquaculture. Few countries offered specialist aquaculture degrees until the sector's recently achieved greater economic prominence.

The preliminary assessment of female graduate rates undertaken indicated that few women were enrolled in the 1970s, but rates rose in subsequent decades (Figure 2 and Table 2). Except in parts of India, most graduate rates (B.Sc., M.Sc. and Ph.D.) are over 30 percent and often closer to parity.

We also found little concordance between the current rates of female graduates and the 2009 national Global Gender Gap rankings (Hausmann, Tyson and Zahidi, 2009). With respect to female aquaculture graduate rates, relatively highly ranked countries such as the UK and the United States of America differed little from countries with much lower gender gap rankings (e.g. Bangladesh, Cambodia and India). Thus, national gender gap rankings do not explain all differences in female rates of aquaculture education, although they may relate to gender differences in later career progress (no data available).

² All those who kindly responded to the survey are mentioned in the Acknowledgements.



In summary, these data indicate that, in all countries (i) the percentage of female graduates in aquaculture increased considerably over the last four decades from zero or low numbers in the 1970s, and (ii) gender ratios of graduates vary by country and even within countries, particularly in heterogeneous countries such as India.

In the case of five institutes, some data were provided on gender ratios among faculty. These indicated that the number of males exceeded those of females in four institutes (6 to 40 percent women) but not in one institution in France (Cnam/Intechmer (DESTA) – 66 percent female).

On graduation, women's and men's career prospects, including salary rates, may differ. Studies are needed to verify the anecdotal information on how gender affects the career paths of graduates. For example, in Asia, women often avoid work involving entering ponds and other physical work during education, preventing them from gaining the full range of practical skills and knowledge needed for career progression. Employers often do not want to put women in the field for safety reasons, also impeding their career paths. In Mexico, field work and gender issues play out in a different way. Working in the field is used by both women and men as a way to gain experience so that they can access better

TABLE 2

Female aquaculture graduate rates in regional, international and country educational institutes. Statistics are given for females as a percentage of total graduates. B.Sc. = bachelor of science and course equivalents in aquaculture; M.Sc. = master of science and course equivalents in aquaculture; Ph.D. = doctor of philosophy and course equivalents in aquaculture. Note that some statistics also include fisheries graduates due to the nature of courses. Where time series were available, the oldest and the most recent rates are given

Institute and programme	Period	Women's graduation rates (N=total number of graduates)
<i>Regional and international institutes and programmes, countries</i>		
Asian Institute of Technology (AIT), Aquaculture and Aquatic Resources Management Programme (AARM)	2003–2008	M.Sc. and Ph.D.: 42% (N=116) Differs by country of origin, e.g. 85% Thailand (N=27); 0% Cambodia (N=9), Indonesia (N=5)
Aquaculture and Aquafish Cooperative Research Support Program (United States of America)	1996–2009	B.Sc.: 44% (N=411) M.Sc.: 37% (N=374) Ph.D.: 34% (N=102)
Countries		
ASIA		
Bangladesh: Bangladesh Agriculture University, Faculty of Fisheries, Mymensingh	1972-2008	Graduates (Unspecified): 32% (2005–2008, N=233); 0% (1972–1974, N=70) (see Figure 2)
Cambodia, Faculty of Fisheries, Royal University of Agriculture	1990-2009	B.Sc.: 20% (2005–2009, N=96); 29% (1990–1994, N=137)
India, Karnataka, College of Fisheries, Mangalore	1980-2009	B.Sc.: 18% (2005–2008, N=156); 6% (1990–1994, N=142) M.Sc.: 19% (2005–2008, N=70); 1% (1980–1984, N=88) Ph.D.: 4% (2005–2008, N=26); 9% (1986–1989, N=11)
India, Kerala, College of Fisheries, Pananagad, Kochi	2004-2009	B.Sc.: 58% (N=223) M.Sc.: 67% (N=27)
India, Tripura, College of Fisheries, Central Agricultural University, Lembuchera	2005-2009	B.Sc.: 29% (N=78)
Thailand, Kasesart University, Faculty of Fisheries	1990-1998	Students: 39% (aquaculture students, N=unknown) (Suwangransi, 2001)
Viet Nam, Nha Trang University	2005-2009	M.Sc.: 40% (N=83)
EUROPE AND NORTH AMERICA		
Belgium, University of Liège	2000-2009	M.Sc.: Belgian graduates, 26% (N= 27); foreign graduates, 16% (N= 113)
France, Halieutes AgroCampus, Rennes	1970-2009	B.Sc.: 46% (2005–2009, N=129); 0% (1970–1974, N=48) (see Figure 2) (French and francophone countries, especially in Africa)
France, Cnam/Intechmer (DESTA)	1991-2010	M.Sc.: 25% (N=191)
United Kingdom, University of Stirling, Institute of Aquaculture	1980-2009	M.Sc. and Ph.D.: 39% (2005–2009, N=unknown); 18% (1980–1984) (see Figure 2)
United States of America, Auburn University, Department of Fisheries and Allied Aquacultures	2000-2010	M.Sc. and Ph.D.: ~40% (N=70–75 graduate students per year)
AFRICA		
Benin, Lycée Agricole Médji de Sékou	2008-2010	Graduates (unspecified): 18% (N=unknown)
Cameroon (no institute specified)	2007-2010	B.Sc.: 80% (N=5)

jobs. Field extension jobs are the main way of gaining field experience. However, field extension jobs are among the worst paid jobs, and this can be a source of corruption, especially when financial support is being given to fish farmers. Also, it means that the extension staff are always young and inexperienced, and thus many are of limited use in helping farmers.

Training and vocational institutions

Gender-disaggregated data on short training courses and vocational programmes are even more dispersed and difficult to access than data for higher education. These data would indicate how practical skills that are of direct relevance to aquaculture are being developed. Some studies have indicated that women's training generally lags behind that of men, partly from low targeting of women for aquaculture technology transfer (extension and adoption) (Nandeesh, 2001) and also from real or perceived lack of job opportunities. Women may be reluctant to attend training programmes due to their heavy responsibilities at home, but this and other constraints such as low literacy levels in some developing countries need to be better understood.

We obtained training and vocational data from one regional institution (the Southeast Asian Fisheries Development Center, Aquaculture Department, SEAFDEC/AQD), one international agency (The WorldFish Center) and several French secondary and postsecondary school vocational institutes.

Since 1990, in the Philippines, SEAFDEC/AQD has achieved about 30 percent female participation in its technical training programmes and 40 percent in its field outreach training programmes that take practical courses to villages. Of particular note, in certain training courses for fishers, such as mud crab culture, the majority of participants were females, whereas male participants were more numerous in training on grouper culture.

At The WorldFish Center's regional aquaculture research facility in Abbassa, Egypt, a marked shift towards greater female participation occurred between 2000–2004 (9 percent) and 2005–2009 (21 percent).

In the French national school system, at the upper and postsecondary school levels, students have a number of options for aquaculture vocational training. The most advanced of these, the BTS (Brevet de technicien supérieur) is for students aged 18–20 years.

Although the data from the French vocational training institutes are not comparable to those for tertiary education graduates, such as Halieutes AgroCampus, Rennes, they show much lower levels of female graduates. Typically, the courses have fewer than 10 percent female participants. Perhaps these levels are closer to those for skilled workers likely to be employed in the private sector than are the present higher levels of women tertiary graduates

(e.g. 46 percent for Halieutes AgroCampus, Rennes). To attract more women to the courses may require more marketing to women and prospective employers of the opportunities for them to work in aquaculture.

Governments are also using training to encourage more people into the aquaculture sector. For example, the state of South Australia, wishing to create local job opportunities and improve local aquaculture performance, offers short-term modular training programmes that are delivered at existing institutions such as selected high schools, vocational colleges, universities and research centers; a range of courses is offered (www.pir.sa.gov.au/aquaculture/products__and__services/training).

Despite statistics showing greater participation by women in aquaculture training, we do not know how many of the women trained actually get involved in aquaculture production. Research would be needed to see if a difference exists.

Other forms of HCD

We have focused on formal education and training, but other forms of (indirect) HCD such as self-help groups (e.g. in India) have proven effective in introducing aquaculture techniques and discussions (Kripa and Surendranathan, 2008). In large aquaculture companies, training is a business imperative, directed at helping employees meet the companies' needs for work safety, product quality, as well as meeting environmental standards. Local and often informal associations and more formalized institutional structures (e.g. producer or marketing cooperatives), when available, would serve as an important vehicle for transferring productivity-enhancing knowledge and techniques in the sector.

HCD, gender and disaster risk management

In the last decade, building the capacity of children, women and men suffering the consequences of natural disasters and diseases has gained greater attention. For example, in Africa, life opportunities for children orphaned due to HIV/AIDS and other vulnerable children, are being created by labour-saving food-producing strategies such as farming fast-growing tilapia (Gordon, 2005). Good examples include the Mangulukeni Fish Farming Project, the work of the Oonte Orphans and Vulnerable Children's Organization, Namibia (M.G. Kibria, personal communication, 2010), and projects in Africa of Aquaculture Without Frontiers (www.aquaculturewithoutfrontiers.org). After the 2004 Indian Ocean tsunami, in Aceh, Indonesia, aid agencies including the Australian Centre for International Agricultural Research (ACIAR) redeveloped the Ujung Batee Regional Brackishwater Aquaculture Development Center and strengthened research management capacity to support the re-establishment of the aquaculture sector (Sammut *et al.*, 2008)

Progress towards meeting the expectations and commitments of the 2000 Bangkok Declaration and strategy for aquaculture development

HCD

The first Key Element of the Bangkok Declaration was *3.1 Investing in people through education and training*. HCD was addressed also in other Key Elements. The progress of HCD in each Key Element of the 2000 Bangkok Declaration is described below.

Key Element 3.1– Investing in people through education and training

Strong progress has been made for Key Element 3.1 in many countries and in some regions, especially Asia and Europe. In this Key Element, HCD was envisaged to be more cost-effective and responsive to needs and attention directed towards participatory curriculum development, cooperation between institutions, multidisciplinary and problem-solving approaches to learning, use of information and communication technology, balancing practical and theoretical approaches.

Despite little attention at the global level, at the country and regional levels, education and training for aquaculture increased nearly everywhere, driven mainly by national economic, food production and educational goals. Although cause and effect have not been studied in the last ten years, the greater national and regional focus on HCD has likely contributed to increased aquaculture production. Evidence from rigorous cost-benefit studies in the agricultural sector has shown that returns on investments in HCD are high and of similar levels to those from research and development investments (Gordon and Chadwick, 2007). In aquaculture, the same is likely to apply.

Of all forms of HCD, education merits special attention because it is the foundation for aquaculture know-how across the spectrum from educating aquaculturists, aquaculture trainers and teachers, researchers, regulators and policy-makers. Many educational institutes are also research institutes helping to create new technologies and solve industry problems. Education helps create the professional base for the sector. Although data are not available, indications are that more M.Sc. and Ph.D. programmes in aquaculture are now offered by more institutes. In countries where aquaculture tertiary studies historically were focused in specialized colleges of fisheries, such as China, India and the Philippines, aquaculture and related courses are now also offered in comprehensive and agricultural universities.

Many higher education programmes in aquaculture are making use of modern education and communication technology, and some of these are described in the section on Future Expectations, Major Issues and Opportunities.

To complement and strengthen the role of the educational institutes, intergovernmental and professional networking has strengthened and matured through institutions and associations such as the Network of Aquaculture Centres in Asia-Pacific (NACA), AFS, WAS, SEAFDEC, and through private-sector and commodity-specific events. In Europe, aquaculture tertiary education institutions are harmonizing and networking their courses and facilities.

In the past decade, training programmes, mainly with a focus on technologies, have also grown in number. Trends in training are difficult to track because the courses are usually short and delivery is dispersed. Often, training is delivered in an integrated manner with development, research and commercial projects. Short training courses often are targeted to impart practical skills in specific aquaculture techniques to potential farmers and entrepreneurs and may be sponsored by government agencies.

Further, developing quality human resources to support aquaculture developments, including innovations made by farmers, will contribute to sustainable development of the aquaculture sector. Farmer innovations are vital but need to be greatly augmented by the farmers' adoption of technologies derived from science and business insights made accessible to capable farmers. Research, technology development, adoption and HCD go hand in hand. This was recognized in the Bangkok Declaration in parts of Key Elements 3.2, 3.3, 3.8 and 3.11 and was addressed during the Global Conference on Aquaculture 2010 (see Expert Panel Review VI.4).

Key Element 3.2 – Investing in research and development, especially capacity of research institutions to be more responsive to development requirement

We have little basis for objectively judging how research institutes have responded to development requirements. However, in the section on Future Directions, we provide examples of how regional organizations such as NACA and SEAFDEC/AQD set priorities and work with partners. Strong national institutes such as Viet Nam's Research Institute for Aquaculture (RIA) 1, RIA 2 and RIA 3 have contributed greatly to supporting the development of their countries in becoming leading aquaculture producers. De Silva and Davy (2009) report many small-scale aquaculture successes.

Key Element 3.3 – Improving information flow and communication, especially strengthening national capacity to determine data requirements and data selection and management

In partnership with member countries, FAO's work is among the most important in addressing this Key Element. For example, FAO has continued to improve national and global aquaculture reporting systems and to build national capacity to meet the global information requirements. The regional specialist agencies and networks such as INFOFISH, NACA, SARNISSA (Sustainable Aquaculture

Research Networks for Sub-Saharan Africa), and SEAFDEC/AQD have all capitalized on modern information technology to disseminate their knowledge over the Internet as well as in hard copy and by direct contact. National agencies such as the aquaculture institutes of the Indian Council for Agricultural Research (ICAR) have also greatly increased their information outreach via their Websites. With the increasing use of Internet technologies, national institutes are expected to accelerate information flow.

Key Element 3.8 – Strengthening institutional support, especially institutional capacity to establish and implement policy and regulatory frameworks

We note that aquaculture developments still often run ahead of policies, environmental and product quality regulations and trade requirements (e.g. the use of antibiotics and the introduction of exotic species such as *Litopenaeus vannamei* in Asia). This suggests that greater attention is needed to better develop the capacity of government aquaculture officials and policy-makers to get ahead of trade and production crises. At present, regional aquaculture agencies, development agencies, non-governmental organizations (NGOs) and the industry are more likely to initiate best practice guidelines and advocate for policy change than national agencies, as occurred in the development of shrimp farming better management practices (BMPs). We therefore conclude that national agencies need to pay greater attention to developing the capacity of their staff to meet trade and regulatory challenges.

Key Element 3.11 – Managing aquatic animal health, especially capacity building at both institutional and farmer levels through education and extension

Aquatic animal health is a particularly challenging area for capacity development, as it requires highly specialized knowledge and skills. During the last decade, HCD included areas pertaining to biosecurity governance (e.g. development of national strategies on aquatic animal health), aquatic epidemiology, surveillance, application of risk analysis and improved diagnostic capacity (both field and laboratory and high technologies, e.g. molecular biology). Developments in the veterinary curricula have also taken place, with aquatic animal health becoming more explicit, particularly at postgraduate levels. More details can be seen in the Expert Panel Review III.3 in this volume.

One of the most successful professional societies in the field of aquatic animal health is the Fish Health Section (FHS) of the AFS. The FHS, composed of aquatic animal health professionals, mainly from Asia, organizes triennial symposia, with the publication of *Diseases in Asian Aquaculture* as one of its major activities. Every Symposium on Diseases in Asian Aquaculture is complemented by offering to participants a continuing professional educational programme on various aspects of aquatic animal health management, taking advantage of the experts attending the symposium. The FHS is the longest-running section of the

AFS, demonstrating its great relevance. The FHS is now in its 24th year, with the 8th Symposium on Diseases in Asian Aquaculture being organized in India, in November 2011.

Gender

Concerning gender, no expectations were expressed in the Bangkok Declaration, although the keynote presentation by Professor T.V.R. Pillay did stress the need to “give due respect” to the involvement and empowerment of women in aquaculture (Pillay, 2001).

Future expectations, major issues and opportunities

In this section, important issues affecting both HCD and gender are elaborated and opportunities to address them are presented.

HCD

Aquaculture is predicted to keep expanding, increasing the world’s reliance on it for fish production. The sector will also confront new (and old) opportunities and challenges, such as production efficiency, sustainability, quality and safety. Will women and men in the sector have the necessary capacity to take the opportunities offered, meet the challenges and overcome setbacks?

At this critical stage in the formation of modern aquaculture, our expectation is that the education and research sectors will take a leading role in developing human capacity. Education and research provide the professional foundations for new, knowledge-intensive aquaculture enterprises. Educational and research institutes must determine the extent to which their aquaculture education programmes and related research focus on large, intensive farming technologies and on small-scale, less intensive technologies that are more suitable for the many poor and small-scale farmers; and on the extent to which environmental and sustainability issues are addressed, as well as achieving a balance between research addressing the present and the future problems for aquaculture.

Issue 1. Accelerated HCD is urgently needed to meet the needs of rapid aquaculture development

The rapid development of aquaculture has created an urgent and growing need to upgrade aquaculture skills and knowledge, maintain the quality of HCD and to do so in an efficient way, such as by taking advantage of new media for delivery. As outlined in Figure 1, coherent HCD across the four levels is needed. We have mainly addressed the first two levels (the individual and the organization) and focused on the educational and training institutions in this review.

Opportunity 1.1 Establish priorities for HCD

More efficient, sustainable and safe aquaculture is also more knowledge intensive, so that the aquaculture sector must simultaneously meet the growing

need for HCD to be delivered more broadly to more people and at a more advanced level to key subsectors. How can the HCD demand for this be met? How can the quality of training and education be maintained and how can such impediments as language be addressed in building human capacity?

How can targeted training and technology dissemination make aquaculture knowledge more relevant and accessible and aquaculture more efficient, sustainable and profitable? New technologies must be relevant to future sector needs and be accessible. How can the needs of aquaculture operators be recognized and addressed in research systems and how will the results of new technologies reach farmers and others in the supply chain faster?

The above concerns create a potentially huge agenda for HCD. They are already the core concerns of government policy and extension agencies and research institutes, and these present hard choices among competing priorities. How agencies set aquaculture programme priorities can provide guidance to setting HCD priorities. Research and development planning and technology dissemination approaches have been codified in priority-setting and technology demonstration and dissemination activities of specialist aquaculture agencies such as SEAFDEC/AQD and NACA and its partner centers of excellence. These agencies begin with aquaculture commodities and aquatic ecosystems as their base unit for planning (. They chart the technology transfer, adoption pathways and client needs for different types of product, and seek feedback. This commodity approach, plus the “farm to fork” and “fork to farm” tracking of needs and solutions are tailored to success at all stages of the value chain. Training needs assessments could be conducted for commodity and production systems and also more broadly for the environment, social, food and market needs. Dissemination methods for new technologies in areas such as fish breeding and farming systems are tailored to different client segments (e.g. hatcheries and farmers). Results are conveyed through a wide range of customized publications that are now widely disseminated on the Internet, as well as at commodity-specific and general conferences and training sessions with accompanying trade exhibitions. Although these dissemination methods may not directly reach many farmers and workers in the supply chain, they do reach those who support and supply them. Specialist agencies such as NACA, SEAFDEC and INFOFISH report that their products are reaching one or two orders of magnitude more users than when they were available only in hard copy, thus also accelerating HCD.

Opportunity 1.2. Cooperate and harmonize work among institutions to address the priorities

The rapid development of aquaculture depends on innovation and access to collective practical and theoretical knowledge. Aquaculture training and education need to achieve a balance between multidisciplinary and specialization and between basic and cutting-edge knowledge. As the technological complexity

of aquaculture increases, the organization of a comprehensive aquaculture curricula requires the combining of transnational or transregional expertise. This has been recognized in Europe through such initiatives as the AQUA-TNET network and by FAO and China with a focus on developing countries through the new unilateral trust-funded training center on aquaculture in China. However, even more cooperation is desirable, not least because, due to unequal growth of aquaculture sectors across regions and countries, friction grows between the need for well-trained workers and highly qualified staff in one place and the dwindling student numbers in another. Transnational knowledge and skilled worker needs have contributed to the growing trend of aquaculture education programmes to rely on student and teaching staff mobility as a means to tap into the required expertise that can no longer be generated entirely in-house. However, before unlimited mobility can be deployed for the benefit of transparent and accessible education, two major challenges need to be resolved: discrepancies in educational systems and language barriers.

Discrepancies in educational systems are tackled on two fronts: harmonization and accreditation. Harmonization is the process whereby educational systems converge towards a common structure that allows seamless exchange of whole or partial educational programmes. Harmonization does not equal uniformity; on the contrary, harmonization fosters the diversity of educational programmes but strives to remove the obstacles that allow learners to access diverse transnational programmes. Accreditation is the second pillar of transparency and accessibility across various educational programmes. Accreditation is the process whereby an independent agency, governmental or non-governmental, carries out the quality insurance and certification – in this case, of educational programmes – according to collectively accepted procedures. Without accreditation, universities and other institutes of higher education will not or cannot grant a diploma based on a curriculum that is partially or entirely pursued elsewhere. Accreditation of educational programmes is an intricate task involving the detailed description of the programme (i.e. coherence, structure, level, objectives, outcomes and assessment), the institute (i.e. staff, infrastructure, facilities) and student-related issues (e.g. selection, admission, tutoring, social and housing services).³ In engineering and medicine, global as well as national accreditation systems apply, helping these sectors to have acceptable common standards across the profession. Such quality standards also facilitate networking courses across and within countries for mobility and wider applicability.

A key challenge is the status of unaccredited short-term sectoral and professional training courses. The European Commission-funded VALLA project (Validation of

³ For example, see European Consortium for Accreditation in higher education (ECA, www.eaconsortium.net). In the Philippines, for example, an agency called the Professional Regulations Commission is responsible for regulating and supervising the practice of professionals who constitute the highly skilled manpower of the country. They provide certification exams for a wide range of courses, including fishery technology.

All Lifelong Learning in Aquaculture: www.vallaproject.com) tested how some types of lifelong learning fitted into the European Qualifications Framework (EQF) (EQF: http://ec.europa.eu/education/lifelong-learning-policy/doc44_en.htm), targeting the aquaculture sector as a pilot case study. The project developed and piloted methods of recognizing and accrediting lifelong learning in the aquaculture sector via the EQF.

Specialist HCD conferences such as the AFS International Symposium on Aquaculture and Fisheries Education (ISAFE, 2009) can help networking among professionals. Professional association conferences such as those of the AFS, WAS, Aquavision and major commodity networks such as the International Symposia for Tilapia in Aquaculture and the INFOFISH commodity conferences could host sessions to identify HCD needs. The FAO Committee on Fisheries Sub-Committee on Aquaculture (COFI/AQ) could take a lead in encouraging global HCD actions. HCD plans must be forward looking so that they help position the sector for future challenges, risks and possible shocks. Risk mitigation strategies must include HCD components, regardless of whether the risk is related to the environment, fish disease, food safety, climate variability and change, or natural and human disasters such as war and economic collapse.

Opportunity 1.3. Address the communication challenges

Language barriers are a major hurdle, as they can make access to materials difficult unless they are translated and can touch sensitive matters involving cultural identity. No simple and global approach exists to solve language barriers. Solutions lie in locally determined tailor-made combinations of (i) the adoption of a “lingua franca” (will this be English and/or Chinese for aquaculture?) and (ii) the inclusion of language training in the curricula. Language issues are most acute in higher education and less so for vocational and professional education and informal learning, as these tend to target the local job market and therefore usually operate in the local language.

Issue 2. Aquaculture education needs to attract the best students and help prepare them for rewarding careers

Over the last decade, as the global economy has boomed, aquaculture faculties have reported difficulties in attracting students, especially the brightest, and even where numbers have grown sharply, such as in China, graduates often prefer jobs outside aquaculture or cannot break into the sector without substantial capital. Some of the course accreditation and mobility solutions discussed above would help attract and retain students, but much more still needs to be done to design the educational systems that are appropriate to the social needs and aspirations of today’s best students against stiff competition from other attractive economic sectors, and to help improve graduates’ employment prospects. Two suggestions are to attune courses to rural settings in which aquaculture operates and to pro-actively market the benefits to high-school students.

Opportunity 2.1. Take aquaculture education and training to rural areas

Aquaculture is typically carried out in rural areas, yet many of the institutes of higher education are located in large cities, giving the students a taste for city life and occupations. Other fields of education grappling with similar challenges, such as attracting sufficient qualified doctors and other professionals to service rural areas, have found that students educated at provincial universities are much more likely to go on to work in rural areas than their counterparts educated in cities.

Opportunity 2.2. Build and project a positive image for aquaculture

The image and prospects for work in the aquaculture sector need substantial improvement. In many countries, the general public hears more in the media about the negative aspects of aquaculture than its positive ones. The sector needs to develop savvy media outreach to overcome this problem, and the aquaculture education institutes should be actively engaged in this process. Aquaculture does attract public interest, as shown by the social networking through electronic outreach by the SARNISSA project (www.sarnissa.org). SARNISSA's Facebook page has 921 followers from among the general public, and the number is growing by the day. About one third of these were women (accessed 26 June 2011).

Opportunity 2.3. Create schemes to develop young aquaculture researchers

In most countries, competition for young professionals is intense among the different economic sectors. Aquaculture research institutes should develop attractive programmes to attract and retain high-quality young researchers for the long term, through scholarships, research awards, mentoring and development.

Issue 3. Aquaculture education urgently needs more social science content

Students in tertiary aquaculture courses do not get exposure to the social sciences, including gender analysis methods and management skills, thus limiting their ability to understand the holistic nature of issues affecting aquaculture development. Core curricula are urgently needed that impart a range of the necessary social science skills and knowledge to all students.

Opportunity 3.1. Increase the social science content of aquaculture courses

The FAO HCD Strategic Framework particularly stresses the importance of social science knowledge and devotes one of the three knowledge and skills groupings to it – societal skills and knowledge. Since the HCD Strategic Framework also stresses the importance of integration of the different knowledge and skills groupings, students not educated in the social sciences are at a disadvantage in functioning well at higher levels in the sector, as these require integrating

skills and knowledge from the three groupings. For aquaculture, these social science skills and knowledge would entail: community mobilization and participation, management and administration (including economics, finance and corporate social responsibility), conflict management and problem solving, good governance, environmental awareness, sustainable trade, information and communications and social literacy, including gender (FAO, 2005).

Gender

Our expectation is that gender equity and equality issues will be placed firmly on the aquaculture policy agenda at all geographical and institutional scales. Attention to gender is needed to help improve women's aquaculture productivity and for human justice. Placing gender on the aquaculture agenda requires a coalition of gender champions, informed researchers, expert networks and policy advocates. Just being aware of the gender dimensions and being gender sensitive are no longer adequate. In society at large, efforts over decades to get more balanced representation/numbers of women and men in the professions, companies and in board rooms have often failed or only marginally succeeded. We expect similar challenges in the aquaculture sector. Already, the fish processing sector has the typical inequity patterns of other sectors. In numbers, women dominate the factory floors all around the world, but few women are in managerial positions, including in countries such as Norway (Husmo, 2005) and New Zealand (Lambeth *et al.*, 2002), despite being the countries with the 3rd and 5th lowest national gender gap, respectively (Hausmann *et al.*, 2009). The aquaculture sector will have to redesign and intensify gender equity and equality programmes, as well as set targets in some institutions to help achieve gender equity.

Issue 1. Gender is ignored in aquaculture

Gender is almost totally overlooked in the global, regional and national aquaculture policy agendas, and little gender-disaggregated information is collected to illuminate the respective contributions of women and men. Commonly, gender is not recognized in sector objectives, plans and private-sector investments, nor in aquaculture and anti-aquaculture advocacy programmes. Activists have focused their attention on the environmental side of aquaculture and paid relatively little attention to the human side, including gender, with the exception of some shrimp farming critiques. Gender is not covered in the *FAO Code of Conduct for Responsible Fisheries* (FAO, 1995), and despite the fact that Goal 3 of the United Nation's 2000 Millennium Development Goals is to "Promote gender equality and empower women", little has been done to translate this in aquaculture. To place gender on the aquaculture agenda, much more knowledge of gender issues is needed. Most policy-makers, researchers and extension officers do not have adequate knowledge of gender issues and the possibilities to improve gender equity and, as a consequence, they are reluctant or simply forget to address gender in their work. They are often not aware of the impact of aquaculture projects on household equity relationships. Private companies in

the supply chain often do not take a proactive approach to the social equity side of the business, seeking least-cost labour solutions for their needs, although they are responsive to product quality and sustainable production issues.

For all the generalizations made above, notable exceptions exist. One comes from the Department of Fisheries, Thailand, which was awarded the 2008 Thailand “Best Practice Award on Gender Mainstreaming”. As Dr D. Prakoboon, then the Director of Fisheries, noted in the 1998 AFS Symposium on Women in Fisheries, 33 percent of the 3 000 officials in the Department of Fisheries were women, including many in high places (Prakoboon, 2001).

Opportunity 1.1. Put gender on the aquaculture policy agendas and include it in normative instruments, starting with a gender stock-take of instruments

All institutions dealing with aquaculture should examine their gender policies and practices and resolve to tackle the dearth of gender-disaggregated data. Although aquaculture alone cannot change deep societal norms of gender inequity and inequality, as a new and growing sector, it has the potential to shake up the societal norms.

With the help of gender experts, FAO and partner aquaculture development agencies should perform a gender stock-take of their aquaculture related normative instruments, policies, programmes and projects and revise their practices to achieve greater gender equity. New policies and standards create the opportunity to incorporate gender awareness from the start. For example, gender should certainly be included in the new FAO certification guidelines under the heading “Minimum substantive criteria for addressing social responsibility in aquaculture certification schemes”. Gender sensitivity in the production of aquaculture commodities could be used as a marketing advantage (selling point) in the future.

Best practice guides and codes of conduct should explicitly address how to achieve gender-equitable social and economic returns in households, communities and companies. These normative instruments could address, among others:

- improved working and social conditions for all people in the industrial aquaculture sector as a normal part of corporate social responsibility;
- equitable access to land/water resources and tenure over these resources by women;
- innovative extension approaches to ensure access to technology and adoption by women as well as men; and
- equitable access to credit, entrepreneurship and management training and business development services by men and women.

Opportunity 1.2. Aquaculture agencies should collect relevant and focused gender-disaggregated information across the range of activities in the sector/value chain, from production to marketing

Gender-disaggregated data are essential to guide and measure the effectiveness of gender policies and actions. FAO should commission a group of experts to draw up guidelines for collecting gender-disaggregated data in aquaculture, drawing on existing work from the agriculture, water, sanitation and household energy sectors. The group of experts should be charged to advise on suitable gender participation and equity indicators that are feasible and cost effective to collect and use at different scales. Indices should be developed for use throughout the supply chain. The expert group should advise on data requirements on the basis of an understanding of gendered structures and needs in the sector, should distinguish data requirements at different scales from global to household and should suggest priorities rather than develop “wish lists” of all possible data. The group should work closely with FAO’s own data collection experts in fisheries and gender. Qualitative as well as quantitative data should be considered. The users of the data should be kept in mind. For example, policy-makers will need different information than those delivering local projects. Different types of data will be collected in different ways, from national statistics to household surveys.

Whereas collecting comprehensive and informative gender-disaggregated data sounds straightforward, experience shows that it entails fundamental reform in the thinking and organization of the agencies involved. In particular, data collection forms will need to be redesigned/modified to make them gender sensitive (with questions such as “how many women” as a minimum). More women will be needed as data collectors/enumerators as, in some contexts, it may be difficult for male enumerators to reach women to ask questions or check information. Government statistics and fisheries/aquaculture departments will need to be more gender aware.

Issue 2. With more women and men in a wider range of aquaculture jobs, the challenge is to create greater gender equity and promote the potential of aquaculture to empower rather than exploit people

Women’s, especially poor women’s, aquaculture roles and responsibilities are often overlooked and considered more menial than those of men, even though they are essential to household food security and industry prosperity. New jobs are often created using substandard employment practices. For example, women in export prawn processing plants in India often work under difficult labour conditions and with few benefits (Nishchith, 2002). In professional jobs (e.g. research, education, regulation), women could offer different insights and perspectives to help research institutes to more fully address the unique and pressing challenges of both female and male farmers (Beintema and Marcantonio, 2010). We are aware, however, that women in power positions often reproduce androcentric views, and their participation does not always

translate into a better understanding of women's problems, unless they are gender aware.

Opportunity 2.1. Address gender equity and equality in aquaculture workplaces

The work conditions for many women, but also many men employed under similar conditions, need attention by employers and labour organizations, just as the International Labour Organization (ILO) has started to address labour conditions in fisheries through the 2007 Work in Fishing Convention.

Many women and women's groups have found aquaculture to be empowering because they have been able to earn decent wages from it and improve their social status in the community and household. How can aquaculture be more empowering for those women already involved and be used to empower those entering the profession? Critical issues to resolve include women's access to resources (e.g. financial, natural, training and market), their mobility and how they are perceived. In Thailand, cage culture was chosen as the income-generating activity for a group of women, and its success raised the recognition that women now enjoy in the village (Sullivan, 2006). In Lao PDR, backyard pond aquaculture was considered more empowering for women than communal waterbody management, because while women were ensured of their access to resources with the private pond, the communal pond gave them little decision-making power (Saphakdy *et al.*, 2009). Experience in Mexico has shown that the participation of men in groups led by women can become a learning experience for equity. It has helped the men recognize the women's contributions from fish farming when, typically, men and children have only recognized women's contributions to the household (i.e. domestic work).

Making women equal partners to men will enable them to improve their families' nutritional and living standards through multifunctional roles, increasing aquaculture productivity and self-reliance. But empowering women can also raise the stress levels within families and in the short-term, work-family conflicts will need to be addressed. However, women will be in a better position to contribute to society's welfare if their needs for adequate skills, knowledge and technologies are met. The objective should be to harness and maximize the respective skills of women and men to work together in harmony for a productive contribution.

The greater involvement of women in aquaculture may raise legal issues such as the need to strengthen the legal framework to provide women access to land, rights to own businesses, and access to education and health and childcare services.

Opportunity 2.2. Raise the technical and management levels of women's aquaculture contributions

For women in aquaculture, a continuing challenge is how to raise the technical and management levels of their contributions and make their participation more rewarding and rewarded. Increasing women's participation and rewards must somehow be achieved with such tactics as greater sharing of household responsibility so as not to increase women's overall heavy work burdens. Educating people in aquaculture technology, therefore, may also include educating women and men in gender equity.

In aquaculture projects, characterizing gender roles can help understand and target technological and other interventions. Agriculture development contains lessons for aquaculture. Reflecting on lessons from agriculture, Padmaja and Bantilan (2008) concluded that: (i) characterizing gender roles helped agriculturists to target women's activities that needed priority technology developments, (ii) women's farm management skills needed special attention, and (iii) social capital and women's access to household assets needed to be understood in addressing technology adoption opportunities and constraints.

Female extension officers and senior staff in aquaculture agencies would also help encourage a more empowered role for women in aquaculture, as they would be able to better communicate with other women. In most countries, however, there are very few female aquaculture extension agents to promote aquaculture. Programmes to attract women to serve as extension agents would serve the dual purpose of broadening the pool of extension officers and promoting gender awareness and women's empowerment at the farm level.

Opportunity 2.3. Promote the good news stories

Promoting the successes of women in aquaculture can have a positive demonstration effect on women thinking of entering the sector. To date, few efforts have been made to capitalize on these examples, learn from them and communicate them effectively to other women and to decision-makers.

Issue 3. Action is needed to enable fair fish trade in the face of rapid changes in supply chains

Regional and trade practices and policies are changing fish trade, including who can trade and who cannot. Also, the trade requirements posed by importing countries can marginalize smaller aquaculturists, especially women who have traditionally traded fish locally but who have less access to the capital, trade regulatory information and technology needed for more distant trade, e.g. in markets with strict quality requirements.

Opportunity 3.1. Foster fair trade in aquaculture products

How can trade policies be made more gender and scale neutral? To date, product accreditation schemes in the fisheries and aquaculture sector have

focused more on environment sustainability and product quality and have not addressed the full spectrum of social equity issues normally embodied in fair trade movements for other products (e.g. see fair-trade.org.uk). Small-scale women fish traders in domestic or transborder supply chains often work “under the radar” of trade promoters and regulators and can be hard hit by shifts in trade. Yet, studies on this trade provide valuable insights into their roles, needs and what actions can assist fair trade. Kusakabe *et al.* (2006), in studying the intricate Cambodia-Thai cross-border fish trade, noted the need for fair and practical fee-paying arrangements, better cold storage to lessen market risks and more fair trade policies to support the development of border regions that benefit from the fish trade.

Opportunity 3.2. Make certification more gender-sensitive

Aquaculture certification is a growing movement, and one that will affect women’s roles and responsibilities in the aquaculture supply chains. In all parts of the supply chain, changes necessary to achieve certification present threats and opportunities to women. For example, on-farm procedures will become more codified and professional, so that if women in a household have been providing unskilled or semiskilled labour, they should be given the opportunity of training to undertake more skilled tasks required by certification. Some forms of certification could put value on accomplishing a minimum percentage of female staff and equity in wages between women and men.

Issue 4. Women are often incorrectly identified with poverty, small-scale farming and limited supply chain roles

The reality of aquaculture is that it can and does provide many opportunities for entrepreneurs through new business models. Women are often considered as only “small aquaculturists” and “backyard aquaculturists”. While these roles for women are important, women’s roles could and do go well beyond these stereotypes. Counter-examples abound. Women are often highly accomplished and have long been respected in the hatchery subsector, e.g., see example of the success of a Vietnamese woman catfish breeder (Little, Tuan and Tu, 1994), a Vietnamese ethnic minority woman awarded by the UN for her work on rural development and empowerment of women through fish farming (L.T. Luu, RIA1, personal communication), an Indonesian shrimp hatchery manager and a Malay semi-intensive grouper and snapper farmer (Brugere *et al.*, 1999). From our personal knowledge in Malaysia, the Philippines, Taiwan POC and Thailand, to name just a few countries, women often hold high positions in activities related to aquaculture, even creating and leading highly entrepreneurial, large commercial companies. For example, from a series of case studies from Taiwan POC, Chao, Chen and Chen (2006) found that the processing side of the sector seemed to provide women with more opportunities to develop artistic and healthy products. Government programmes helped women entrepreneurs, and the new Internet age assisted women to grow domestic and global businesses, starting from a low-cost base and without relocating from home districts.

Opportunity 4.1. Stop stereotyping women as only “small-scale and backyard” aquaculturists

Stereotyping women limits the HCD activities they can access. The growing number of women graduating with higher degrees in aquaculture indicate that a breakthrough is underway, at least in levels of women's education. Despite this, many women find difficulty in obtaining higher-level posts. In the industry side, Bangladesh has provided interesting insights into how mobile phones can be used to overcome many of the gendered obstacles in aquaculture (e.g. access to market information and extension services). In Viet Nam, women were able to bid for concessions for cage culture in a large community reservoir, thus showing their management capacity to organize large-scale aquaculture (Kusakabe, 2001). In Thailand, there is little restriction in women's mobility, but women generally chose not to leave their homesteads because of their responsibilities to look after the household, the fish and the livestock (Sullivan, 2006). The study of Kusakabe *et al.* (2004) showed that women used mobile phones to contact fish merchants and fisheries officers more often than men, indicating that new communication technologies can help to overcome their lack of mobility. In the household, women who had more information on aquaculture technology had more say in aquaculture production decisions compared to those who were more involved in aquaculture labour and had less access to technological information and knowledge.

Opportunity 4.2. Improve access of women to higher education in aquaculture

In higher education and research, telecommunications could be further used. Distance learning opportunities could be designed to improve access for women. The University of Stirling-Bangladesh Agricultural University postgraduate programme in aquatic resource development is using distance education to reduce the relatively high drop-out rate of high-quality women candidates.

HCD and Gender

The Expert Panel noted that the social changes affecting aquaculture often have joint HCD and gender implications. Here, we highlight two specific future expectations that affect both HCD and gender – the pressures of men working away from the home and women faculty.

Issue 1. Men's labour mobility in rural areas places increased pressure on women

Based on experience with small-scale aquaculture projects in developing countries such as Nepal and Mexico, out-migration of men from rural areas is common and women are left to take responsibility for farms and households.

Opportunity 1.1. Aquaculture can provide good livelihood opportunities for rural women

Aquaculture can provide better alternatives to livestock, vegetables and other crops, as it requires less labour. Consequently, providing training to women

in rural areas where men are absent is becoming a common need. In Nepal, women work in groups that identify their leaders. The chosen leaders will be key to the enduring success and further expansion of aquaculture. Beyond new technologies, training should include leadership skills such as group organization, effective communication, business development, accounting and financial management. In many countries, special attention should be given to indigenous women.

Issue 2. Aquaculture faculty are predominantly male

Although we were not able to obtain extensive data on current faculty composition, our observations and first-hand experience indicate a gender imbalance among teaching faculties/educators, not limited only to Asia and developing countries. For instance, when AIT gave high priority to the participation of women faculty in curriculum development and in creating a network of thematic specialists, based on the suggestion of the EU, it found very few (10 percent of 20 specialists) women available in four Asian partner universities (i.e. Royal University of Agriculture, Phnom Penh, Cambodia; RIA No. 1, Hanoi, Viet Nam; University of Aquaculture and Fisheries, Ho Chi Minh City, Viet Nam; and Institute of Aquaculture and Agriculture, Tribhuvan University, Nepal).

Opportunity 2.1. Improve the gender balance of faculty in aquaculture education institutes

Gender policies and programmes such as enriching the pool of women applicants are urgently needed to increase the ratio of female:male faculty members in academic institutions. This policy has to address the base-level faculty as well as more senior staff. Some Expert Panel members felt that women may not be attracted to aquaculture teaching positions, despite women's scholarships such as the Norwegian Agency for Development (NORAD) Scholarships at AARM/AIT. Higher education institutes should consider such affirmative action as setting minimum target numbers for women faculty or giving preference to women where other factors are equal, advertisements that target women, ensuring post-degree career opportunities/employment for women and, in aquaculture courses, promoting side disciplines such as training, extension, economics and management. In the case of the latter, these side-disciplines are less hands-on technical subjects. In subjects requiring field work, women (and indeed people) friendly field equipment should be promoted, e.g. use of water-proof trousers for entering the ponds, lighter equipment and engines.

Opportunity 2.2. Learn from initiatives in agricultural science

The aquaculture sector could learn from recent agricultural initiatives. For example, the AWARD (African Women in Agricultural Research and Development) programme, which also includes aquaculture researchers, (<http://www.genderdiversity.cgiar.org/resource/award.asp>) is paying renewed attention to the joint needs for gender equity and strengthening scientific competence, seeing women as a vital resource in science.

Recommendations from the expert panel presentations during the Global Conference on Aquaculture (GCA) 2010

Expert Panel VI.3 – *Addressing HCD and gender issues in the aquaculture sector* was one of four expert themes under Thematic Session VI – *Enhancing the contribution of aquaculture to poverty alleviation, food security and rural development*. The three others were: Expert Panel VI.1 – *Protecting small-scale farmers: a reality within a globalised economy?*; Expert Panel VI.2 – *Alleviating poverty through aquaculture: how can we improve?*; and Expert Panel VI.4 – *Supporting farmer innovations, disseminating indigenous knowledge and aquaculture success stories*. Although located within Thematic Session VI, Expert Panel VI.3 has gone beyond poverty alleviation, food security and rural development in addressing HCD and gender issues, as these also have critical wider importance. From the many above Issues and Opportunities, a set of key recommendations were presented and discussed at the 2010 GCA, as follows:

- Include HCD and especially gender in the Phuket Declaration! Make sure that statistics are gender disaggregated.
- Tackle data collection requirements to document gender roles and relations throughout the aquaculture value chain and to assess training and educational needs at all levels in aquaculture.
- Promote the inclusion of social science disciplines (including business administration, sociology, anthropology and geography development studies) in aquaculture curricula and training to keep up with the broader needs of aquaculture development. Support the formation of platforms/networks of professionals to enhance the sharing of information and experiences, and facilitate harmonization of curricula and integration of women in the profession.
- Make assessment of institutional arrangements (e.g. legal framework and entitlements), organizational culture and practices and curricula from a gender perspective to create an enabling working environment for women and men professionals and farmers.

In addition, The Phuket Consensus (FAO/NACA/Department of Fisheries Thailand, 2010) contained the following on HCD and gender:

- HCD: (from Preamble) re-affirmed implicitly commitment to the 2000 Bangkok Declaration and Strategy. “...the Strategy continues to be relevant to the aquaculture development needs and aspirations of States.”
- Gender: Recommendation “5. Support gender sensitive policies and implement programmes that facilitate economic, social and political empowerment of women through their active participation in aquaculture development, in line with the globally accepted principles of gender equality and women’s empowerment.”

The way forward

HCD and gender issues are at the heart of the future development of sustainable aquaculture. As the global leader, FAO should place HCD and gender firmly in its programmes, lead in developing methods for collecting gender-disaggregated information and select suitable indicators to track progress of gender equality and equity. The FAO HCD Strategic Framework should be adapted for future aquaculture needs, augmented to strongly incorporate gender equity and equality and adopted to guide the work programme for aquaculture.

When formulating the HCD and gender work programme priorities, FAO should look not only at the people in aquaculture production but include those engaged throughout aquaculture supply chains and address issues such as the gender impacts and gender vulnerabilities of the sector to market and social changes.

In light of the ongoing world food security challenges, the conditions in which poor women and men farmers practice aquaculture should receive special attention and be included in education and training priorities. Professional bodies should host substantial expert sessions on HCD and gender within their conferences, publications and work programmes.

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Supporting farmer innovations, recognizing indigenous knowledge and disseminating success stories

Expert Panel Review 6.4

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Abstract

The term “innovative farmers” refers to those who have tried or are trying out new and often value-adding practices, using their own knowledge and wisdom or through appropriation of outsiders’ knowledge. It has been recognized that farmers’ innovations are crucial in order to achieve cumulative growth, both economically and socially. In most cases, farmers’ innovations are encouraged by the need to maintain economically viable production; in other cases, social needs such as food security are also drivers for innovation to increase income. Environmental sustainability, such as preservation or restoration of local species, has also been a driver of innovations in some regions. However, several social, political, economic and environmental factors have hampered farmers’ innovation; these include lack of information on aquaculture, inadequate science and technology policies and lack of governmental support. At the commercial level, fish farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology. In terms of organization, innovation is a process that requires science to support technology development that is applicable to production.

Crucial factors needed to promote, encourage and support farmers’ innovative processes are presented and discussed in this review, including changes in science and technology laws to promote knowledge-based adaptations, specific policies to encourage investment in innovation, educational policies focussed on developing specific profiles to manage technology-based aquaculture, appropriate personnel training and extension services, and policies that contribute to the development of aquaculture directed to specific social and cultural groups. Proper design interventions and policies can help to bring a much needed empathetic understanding and holistic vision in order to connect and integrate the various innovative efforts towards a positive outcome. These could provide adequate guidelines for developing countries in order to become transformed into innovation-driven economies.

The concepts of farmers’ innovations are assessed from a broad spectrum of geographical areas and farming systems, and how these innovations have contributed and can contribute to food security, poverty alleviation and

sustainability is described. Successful interactions between science, technology and production which have contributed to innovation in both small-scale and commercial aquaculture are examined.

Equally important is the recognition of indigenous aquaculture practices all over the world; there are numerous examples that illustrate the good use of traditional knowledge in developing cost-effective and sustainable strategies to enhance poverty alleviation and income generation, in both developing and developed countries. We evaluate how indigenous knowledge principles can be used to promote environmentally friendly aquaculture practices.

Traditional knowledge is an important part of the lives of the poor: it is the basis for decision-making of communities in food security, health, education and natural resource management. We thus focus on how this knowledge has been adapted, applied and disseminated.

The case studies presented are expected to provide pathways to build effective partnerships between farmers, researchers and policy-makers; some of the major traditional knowledge has been subjected to scientific validation, and attempts have been made to improve them through the application of science-based approaches. However, there is a paucity of information on the vast amount of traditional knowledge that is prevalent in different societies and cultures all over the world.

Furthermore, we assess several strategies used for the dissemination of success stories, including both traditional and emerging approaches which have been effectively applied within the aquaculture sector development. Studies clearly reflect that wherever farmers have had access to adequate foundation knowledge on the science of a technology, they have been able to constantly improve the production systems, assuring sustainability and adaptation to local conditions. Examples that demonstrate how successful technologies and practices have been disseminated through different approaches are presented. For instance, the establishment of farmer field schools, cluster approaches and self-help groups in many locations of the world, as a way to transfer appropriate aquaculture technology is discussed and assessed. Moreover, dissemination methodologies followed by some of the most relevant regional aquaculture networks are also presented.

Lastly, we examine the extent that indigenous knowledge, farmers' innovations and innovative dissemination strategies have contributed to the rapid growth of the aquaculture sector in different parts of the world, and how these practices could be adequately documented and disseminated in the future. Further, we assess the need to promote effective partnerships between farmers and the scientific community; while the conventional dissemination strategies would help to spread the technology in a given location, newer institutional approaches and electronic systems can be used to cross geographical boundaries.

KEY WORDS: *Aquaculture, Indigenous knowledge, Information dissemination, Innovation, Success stories.*

Introduction

Aquaculture remained as the fastest-growing food production sector in the last decade, and without any doubt, the Bangkok Declaration, endorsed in 2000, has provided during the past decade, and will provide during the forthcoming years, the necessary guidelines to stimulate and promote the development of a sustainable and environmentally friendly aquaculture sector globally. The present report aims at assessing how indigenous knowledge and fish farmers' innovations have also contributed to global aquaculture development, and what types of strategy can be designed to safeguard and promote traditional and indigenous techniques wherever they exist. We also analyze and suggest appropriate mechanisms to build greater linkages between farmer innovators and the scientific community, in order to hasten the process of sustainable aquaculture development. Lastly, we identify and assess successful dissemination strategies that have contributed to the rapid development of aquaculture in the past decade and in various parts of the world, and suggest efficient and feasible ways of disseminating information to reach relevant stakeholders at all levels of the production chain.

Regarding fish farmer innovations and their linkage with small-scale aquaculture, we note that Asia has been the center of aquaculture production for decades, and currently, more than 90 percent of the total aquaculture production (in quantity) comes from Asian countries, China being the biggest producer in the world (FAO 2010). What is most interesting regarding these data is that more than 70 percent of the total aquaculture production comes from small-scale farmers producing in semi-intensive or semi-extensive farming systems, and who are also the major contributors of small-scale innovations and adaptations of aquaculture technologies developed in more developed regions of the world to suit their own local conditions. In many countries of the world where the required natural resources for aquaculture development are available but access to modern technologies is limited, thanks to the innovative potentials of farmers and through adaptation processes, farmers' innovations have been evolved and adapted to increase aquaculture production during the past decade (Edwards, 2009d, Nandeesha, 2007).

Examples will highlight the innovative potential of farmers, as well as the role of productive partnerships between farmers and scientists. Combined efforts between farmers and scientists have contributed to the rapid development of aquaculture in countries where resources were available and market demand for aquaculture products was present (De Silva and Davy, 2010). Furthermore, these fruitful farmer-scientist partnerships have shown that relevant technical constraints can be efficiently solved by involving farmers in the development process, since they have the field experience and the environmental wisdom

that is needed. On the other hand, the implementation of adequate policies designed to stimulate and promote farmers' innovations has demonstrated the real benefit of involving a broad range of stakeholders in the expansion of the sector. As an example, India founded the National Innovation Foundation in order to promote grass-roots level innovations, having achieved amazing results that are discussed further in this paper (Nandeesh, 2007).

Lastly, there are several successful examples of technology transfer and dissemination strategies that have had major impact on aquaculture development in the past decade. Modern information and communications technologies (ICTs) have been and will be incredible dissemination strategies with minimal cost: electronic communication systems are nowadays helping to reach the masses with minimum efforts.

Bangkok Declaration: commitments and progress made

In the Bangkok Declaration, although there is no explicit statement on the three main components addressed by this review, namely: indigenous knowledge, farmer innovations and dissemination of aquaculture technology and information, the spirit behind these concepts can be traced in some of the statements made under different categories in the Bangkok declaration. For example, the statements made under Key Element 3.2 *Investing in research and development* clearly indicate that “stakeholder participation in research identification and implementation” should be considered as a key factor to accelerate finding solutions to problems. Similarly, under Key Element 3.3 *Improving information flow and communication*, there is an explicit statement on “making effective use of new technologies to improve information flows and management policies and practices within aquaculture”. Substantial progress has been made regarding this specific topic during the past decade: technology transfer strategies and dissemination approaches have evolved amazingly during these last ten years, and illuminating and didactic examples of dissemination strategies will be described and analyzed.

In the sections presented below, we describe the progress accomplished, the challenges encountered and the suggested way forward to address the main gaps, limitations and constraints. In addition, evidence to provide special emphasis on safeguarding traditional knowledge for the benefit of humanity is also presented. Regarding farmer innovations, a broad range of illuminating case studies from all regions of the world and all types of production systems is analyzed and discussed, as well as the main limiting and promoting factors for innovation. The past decade has best witnessed the impact of information and communications technology (ICT) in all walks of life, and similar impact is witnessed in aquaculture. Opportunities to further scale up these positive developments to sustain and increase aquaculture production in the coming decade are detailed.

Recognizing indigenous knowledge

Concepts and background

This section presents examples and case studies which illustrate the amazing scope of indigenous and traditional wisdom existing in relation to aquatic production systems which are providing food and income to several thousands of families dependent on them.

The term “ indigenous or traditional knowledge” is defined as “the knowledge stored in people’s memories and activities, and expressed in the form of stories, songs, proverbs, dances, myths, folklore, cultural values, beliefs, rituals, community laws, local language and taxonomy, agricultural practices, equipment materials, plant species and animal breeds” (Grenier, 1998). Indigenous information systems are cumulative, dynamic, continually influenced by internal creativity and experimentation, as well as by contact with external systems (Flavier, De Jesus and Mavfarro, 1995). In many rural areas, the traditionally associated technical knowledge of fish farmers has been followed for generations to overcome different situational constraints (Gupta, 1990,). Farmers’ traditional adaptations and innovations have little or no cost; they are readily available, socially acceptable, economically feasible and sustainable; they involve minimum risk to rural farmers and producers, and they are widely believed to conserve resources (Goswami, Mondal and Dana, 2006). The use of farmers’ innovation, skills and wisdom promotes active community involvement because people depend more on each other; farmers’ innovations encourage transparency and accountability (Ratnakar and Reddy, 1991). Indigenous knowledge contributes to the increased efficiency, effectiveness and sustainability of the development process (Rao, 2006). Regarding aquaculture, indigenous traditional knowledge of farmers all over the world has resulted in the development of sustainable and environmentally friendly aquaculture practices; some of the most relevant ones are presented in the following sections.

As will be described in the next sections, most of the indigenous and traditional practices are based on integrated approaches, where agriculture and/or livestock production are being integrated with fish farming as a way to increase natural resources efficiency and diversify income-generating activities. For instance, with regard to indigenous and traditional aquaculture strategies, rice-fish culture is considered among the most basic and may be the most ancient type of traditional integrated fish farming system in the world. Recent archaeological evidence has indicated the possible co-evolution of agriculture and integrated aquaculture systems since more than 8 000 years ago in China, where the earliest evidence of integrated fish-rice culture dates from 1775–1780 BP (Edwards, 2004). In India, where traditional aquaculture was mainly practiced along the coastline by fisheries communities, the most ancient traditional fish farming systems include the bheri system in West Bengal, the gheri system in Orissa, the pokkali system in Kerala, and the khar lands or gazani (coastal khar lands) in Karnataka; all of

these will be analyzed in detail in the sections which follow. It should be noted that most of these traditional Indian systems are also integrated agriculture-aquaculture strategies that integrate fish production with rice or other crop cultivation (Jhingran, 1991; Sonak, Kazi and Abraham, 2005).

Integrated agrolivestock-fish production

Edwards, Pullin, and Gartner (1988) defined integrated aquaculture as “the concurrent or sequential linkage between two or more farm activities, of which at least one is aquaculture”. Multitrophic aquaculture approaches and integrated fish farming systems such as crop-livestock-fish culture integration were developed by Chinese farmers thousands of years ago (FAO/ICLARM/IIRR, 2001), and they are still playing a major role as nutrient-recycling strategies in many developing countries of the world. In China itself, farmers are slowly moving from integration and polyculture systems towards more intensive monoculture strategies (Edwards 2009d); however, a considerable number of fish farmers still actively practice integrated farming in Asia and other regions of the world. At present, the integration of fish and agrolivestock production is becoming more relevant than ever in developed countries as an alternative to intensive and highly unsustainable farming strategies. Integrated farming is a green approach, an environmentally friendly strategy and a sustainable practice (Little and Edwards 2003; Edwards, 2006a,b). In Asia, fish culture in semi-intensive systems mainly depends on fertilizer nutrients. Moreover, with increasing need for multipurpose use of water resources, community waterbodies used for watering livestock are increasingly stocked with fish seed and their management intensified. Several studies of small-holder aquaculture in Bangladesh, India, Thailand and Viet Nam indicate that livestock wastes are the most commonly used inputs as organic fertilizers or supplemental feeding inputs (Edwards, 2008a,b, 2009a,b,c,d, 2010a,b,c,d). Fish yields may not be optimized for a variety of reasons, but livestock wastes purposely used in ponds or draining into them support the production of most cultured fish in Asia (Little and Edwards, 2003). The main linkages between livestock and fish production involve the direct use of livestock wastes, as well as the recycling of manure-based nutrients which function as fertilizers to stimulate the natural food web. The recycling of animal wastes in fish ponds as a major feeding source is important to small and medium-scale aquaculture practices all over the globe, in order to reduce expenditure on costly feeds and fertilizers, which could be more than 50 percent of the total input cost of a productive system. However, indiscriminate use of these manures in fishponds, instead of improving pond productivity, may lead to uncontrolled eutrophication, hypoxia and pollution (Edwards, 2008b). Integrated biosystems can be relatively sustainable and resilient, and have the potential to create a big positive impact on local economies (; Nandeesh, 2007; Edwards, 2009d). Although some infectious diseases (zoonoses and non-zoonoses) such as the swine flu and bird flu pandemics have created several animal and human health concerns regarding the possible biosecurity approaches to integration, the systems continue to provide a good opportunity to recycle animal and

vegetable wastes as a key resource for poor farmers; integration at the family level continues to flourish in Asian and African aquaculture.

Integrated rice fish culture

Rice-fish culture is another traditional integrated food production system focused on integrated fish farming, which has, as well, a quite long history (Halwart 1998; Halwart and Gupta 2004). It has been considered the oldest type of “co-evolution” of agriculture and aquaculture production, with more than 8 000 years of history in China (Edwards, 2004). Modern rice-fish culture systems supported by well-constructed infrastructures, fish ponds and trenches, improved supplementary feeding practices and intensive management approaches are an outcome of farmers’ self-learning through generations.

The rice-fish culture system as a source of food appears to be the oldest form of integration practiced by mankind. Cultivating rice and fish together has been a 2 000-year-old tradition in some parts of Southeast Asia (Halwart, 1998; Halwart and Gupta, 2004). The lowland societies of these regions of the world have been described as “rice–fish cultures”, such is the importance and interconnection of these two basic food sources and production systems (Gregory and Guttman, 2002). Rice-fish cultivation continues to be practiced in rain-fed and irrigated rice fields, and in upland terraced and lowland rice fields.

Rice-fish culture practices have demonstrated benefits in terms of increasing rice yields and also providing farmers with additional income. Implementation of a rice-fish culture system is relatively easy and an inexpensive culture strategy; in rice-fish culture strategies, fish are both cultured and captured as a by-product of rice cultivation, along with a wide variety of other aquatic organisms that contribute to local diets (Halwart, 2006). Both concurrent rice–fish culture in the shallower flooded areas and also alternating rice and fish culture in the deep-flooded areas of Bangladesh, through a community-based management system, have been tested and disseminated to farmers (Halwart, 1995; Dey and Prein, 2004) and with necessary local adaptations are considered suitable also for other regions in the world (Halwart and van Dam, 2006; Halwart and Settle, 2008). Organic rice cultivation practices combined with fish cultivation in paddy fields by the indigenous people (the Apatani tribe) in Arunachal Pradesh, India have shown the possibility of getting up to 5 tonnes of rice/ha and an average of 500 kg fish/ha. In this rice-fish culture system, farmers dig a small pond or trench in a low-lying area of the rice field that acts as a refuge for the fish during planting and harvesting or when there is little or no water. This system also allows farmers to keep fish alive after the growing season. Soil excavated is used to raise the dykes around the paddy field, which controls water levels and is also used to implement horticulture. Once the field is flooded, rice is planted, and once the paddy is established, fish are released. During harvest, water is drained and fish are collected. Some of the most relevant benefits of this integrated system include recycling of nutrients,

increase in uptake of nutrients (e.g. phosphorus and nitrogen) by rice, increase in rice yields, reduction of dependence on external inputs such as fish feeds, chemical fertilizers and pesticides, reduction of pests, conservation of aquatic biodiversity, diversification of income-generating activities, income increase by farmers and increase in the availability of high-quality protein.

Traditional integrated aquaculture systems in India – policy interventions

Rice-fish culture implemented in intertidal brackishwater areas is prevalent in many countries, as will be described in several case studies in this paper, and it is geographically based on the locations adjoining the sea. In India, there are four geographical regions, with four different and specific integrated farming systems strategies being implemented as brackishwater rice-fish approaches, namely: pokkali paddy fields in Kerala, bheries in West Bengal, the khazan system of Goa and the gajani system of Karnataka (Jhingran, 1991-). These systems are still being implemented as efficient farming strategies adapted to very specific locations and as a way to provide an alternative and efficient use of brackishwater areas, thanks to specific farmer innovations developed to suit local conditions. The pokkali field, a unique ecosystem covering an area of 1 250 000 ha, is a traditional fish culture system in Kerala, India (Ranga, 2006). It is a shrimp culture filtration practice commonly known as “chemmeen kettu” and is normally practiced after rice harvest, but not always. The raising of fish and crustaceans in paddy fields, either together with rice or after harvest, is a very traditional practice. Wild shrimp and fish seed brought into the field through tidal water are trapped in the pokkali and allowed to grow for four to five months. In this system, no selective stocking or supplementary feeding is done. Vegetable wastes from the pokkali rice cultivation provide the required natural feed material for fish culture, meeting all fish requirements. At low tide, fish are caught in the sluice net. Trapped fish and crustaceans are harvested when they reach a marketable size. Nowadays, the pokkali paddy fields are not such a profitable venture, due to the increasing cost of human labour; nevertheless, since the flesh taste and quality of this specific production system are quite valuable and popular, the system is being promoted and maintained by some governmental and private initiatives.

The bheri system is implemented nowadays in West Bengal. It is generally larger in size and based on a different type of location; this system is either used for rice-fish culture or for fish monoculture. Most bheries are used for fish culture using the Kolkata city domestic sewage as the feeding source (Nandeesh, 2002b; Edwards, 2008c). This technique of sewage-fed system is considered to be unique, and it is the largest system under sewage-fed fish culture in the world, utilizing domestic sewage as the primary feeding source to produce consumable products. The early success of fish culture in stabilized sewage ponds that were also used as a source of water for growing vegetables provided a stimulus for the large-scale expansion of sewage-fed fish culture. The area

under this unique system of culture peaked at 12 000 ha; in recent years, there has been a steep decline in the total production area due to the increasing pressure from urbanization. However, the government has issued new legislation in order to conserve these wet lands and to prevent illegal utilization of bheries for urban settlements (Nandeesh, 2002b; Bunting, *et.al.*, 2004).

The khazan system of rice-fish culture is practiced along the coast of Goa, India, and is an example of a community-managed agriculture-aquaculture integrated ecosystem. The history of the system dates back to the sixth century (Sonak, Kazi and Abraham, 2005). This system was developed by local farmers who used their traditional knowledge on climate, tidal cycles, geomorphology, monsoon precipitation, runoff, sediment dynamics, soil properties and drainage characteristics of estuarine lands, in order to develop a suitable practice (Anon., 1992). The production system is located in the mangroves, which have been reclaimed using a system of dykes, canals and gates. The traditional and highly adapted khazan technology is based on the principle of salinity regulation and tidal clock. The system is currently under threat due to urban growth; thus, efforts are being made to preserve this traditional fish farming technology.

Periphyton-based fish culture

The acadja practice of West Africa was first described by Welcomme (1972) based on the practices followed in western African countries to capture fish through trapping by establishing periphyton-based food production systems. The most interesting aspect is that these periphyton-based practices have been developed independently in various geographical locations all over the world, following a very similar strategy. For example, similar methods are also prevalent in Asia and Latin America, such as the katha fishery in Bangladesh, the samarah fishery in Cambodia and shrimp and crayfish production in Mexico. The idea of using periphyton techniques in ponds, based on traditional farmers' practices, has attracted a wide research interest (Azim *et al.*, 2005). Bamboo stems, jute sticks, the remains of sugarcane stalks and tree branches are all used as the substrate. The aim of the practice is to increase fish production without increasing the level of nutrient inputs (Wahab *et al.*, 2001; Azim *et al.*, 2001; Keshavanath and Wahab, 2001; Verdegem and Azim, 2001). The practice originated from indigenous knowledge to attract fish, and fish farmers have found easy and feasible ways to understand its principle and apply it in aquaculture. Results clearly demonstrate the scope to increase fish and shrimp production by using the periphyton system and some of the progressive farmers are reaping the benefits through further on farm innovations.

Guinea Bissau: traditional integrated farming systems in mangroves areas

This traditional aquaculture system has been practiced in Guinea Bissau from ancient times and is based on the integration of the culture of indigenous tilapia species with rice production, mostly in brackishwaters located in mangrove

areas. Farmers have applied their traditional and field-based wisdom on tidal cycles, sediment dynamics, soil properties and drainage characteristics of estuarine lands in order to develop a suitable integrated farming practice. There are two types of system being implemented in the coastal areas of Guinea Bissau: one system could be considered as the most ancient or traditional one and the second could be considered as the improved version of the traditional strategy. Fish harvesting is done once in a season, just after the rice harvest. The so called “traditional” system is based on the construction of a main dam and secondary dykes to regulate the entrance of seawater and to facilitate the storage of rainfall water into the rice field, in order to create a brackish environment appropriate for rice and fish culture. The main dam could be about 10 m in height, depending on the size of the field; secondary dikes also vary according to the dam’s size. The antisalt dikes have three or four openings made by the trunks of palm trees and placed at the lowest point on the perimeter for evacuation and control of water in the rice field area. These antisalt systems have two main objectives: (i) to protect the rice fields against salt water brought by the high tide and (ii) to store rainwater in order to create favourable environmental conditions to culture irrigated rice.

The most common species being cultured are *Tilapia* spp. and *Clarias* spp., as both can tolerate high salinity rates. This “artificial” ecosystem created by rainfall water mixed with sea water decreases the number of predatory species less tolerant to low salinity.

The second type, the “innovative or improved” system, is based on the use of polyvinyl chloride (PVC) pipes instead of palm trunks for the openings and/or drainages, and wider and stronger dykes compared to the traditional system. Management principles remain the same. No supplemental feeding is done. This system is mostly located in the coastal regions in the south and northwest of Guinea Bissau (e.g. the region of Biombo and marine areas of northern and western Quinara and Tombali).

The major advantages of this traditional system are that the infrastructure, technology and inputs needed are available locally; that rice is the staple food for all communities in the areas concerned; and that there is a high concentration of producers in the same valleys which would allow communal management to be developed. Major constraints include that the system has to be technically sound and socially acceptable, and thus water management practices are needed – dams and dikes should be built solidly in order to minimize erosion; that the lack of technical information needs to be solved in order to optimize the culture system (e.g. biological information on species and production cycles); and that problems in accessing the rice fields during the rainy season need to be addressed.

Successful governmental approaches to documentation and validation of indigenous agriculture practices in India

The Indian Council of Agricultural Research (ICAR) undertook a major project to document relevant indigenous practices prevalent in various parts of the country, as well as to verify indigenous systems through scientific investigation. This massive study has resulted in the compilation of more than 100 agriculture-based indigenous strategies. However, this initiative didn't assess indigenous systems prevalent in aquaculture production (Das, et.al., 2004). Currently, a study by the Central Institute of Fisheries Education is documenting and validating relevant indigenous aquaculture and fisheries systems in different parts of the country.

Supporting farmers' innovations in aquaculture

Concepts and background

The term “innovative farmers” refers to those who have tried or are trying out new and often value-adding practices, using their own knowledge and wisdom but also through appropriation of outsiders' knowledge (Nandeesh, 2007). It has been recognized that farmers' innovations are crucial in order to achieve cumulative growth, both economically and socially. In most cases, farmers' innovations are encouraged by the need to maintain the economic viability of production systems. In other cases, social needs such as food security and increased income or cultural background are also drivers for innovation. Environmental sustainability, such as the desire to preserve or restore local species, has also been a driver of innovations in some regions (Reji and Waters-Bayer, 2001).

However, several social, political, economic and environmental factors have hampered farmers' innovation; these include a lack of quality information on aquaculture that will encourage farmers to engage in innovation, inadequate science and technology policies and a lack of governmental support. At the commercial level, fish farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology.

Innovation is a process that requires science to support technology development that is applicable to production. Proper design interventions and policies would help to bring much needed empathetic understanding and holistic vision to connect and integrate the various innovative efforts towards a positive outcome. These could provide vital directions for developing countries to transform into innovation-driven economies.

We have observed that some of the crucial factors to promote, encourage and support farmers' innovative processes are related to changes in science and technology laws, focused on promoting knowledge-based innovations. There is also a need for specific policies to enhance investment in innovation, educational

policies to focus on developing specific profiles to manage technology-based aquaculture, appropriate personnel training and extension services, and policies that contribute to the development of aquaculture directed to specific social and cultural groups.

In this section, we present information on the major innovations that have occurred around the world thanks to farmers' initiative.

Farmers' innovations – the role of the Food and Agriculture Organization of the United Nations (FAO) in compiling and validating successful experiences

FAO provided the necessary forum and platform to share and discuss farmer innovations during the workshop on “Assessment of fish seed resources for sustainable aquaculture” (Bondad-Reantaso, 2007). Innovations related to fish seed production, with a special emphasis on women as producers, highlighted a number of innovations made by farmers in various Asian countries. This workshop pointed out that through productive partnerships between farmers and scientists, many technical issues can be solved by combining the field experience of farmers and the ability of researchers to access relevant information and develop intervention strategies. The study also suggested that documentation of farmer innovations from all over the world was very poor, and that the available information was weak and scattered. The possibility of establishing a database to include farmer innovations from all regions of the world was mentioned, to provide free access to stakeholders.

In this section, we have made an effort to capture significant innovations of farmers that have contributed to the development of aquaculture. There are several farmer innovations that can be tracked and classified as adaptive research; there are also path-breaking innovations made by farmers that have transformed the livelihoods of several thousands of farmers. These examples clearly demonstrate the success and sustainability of such innovations through partnership efforts.

Overview of the main innovations in China

Farmer's innovation in China may be traced back to its historical roots in the 5th century B.C., when Fan Li first tested culture of carps. The construction of earthen spawning ponds simulating the carp's natural environment is still a major technique used in fish spawning.

The polyculture system used in China has been refined and improved by Chinese farmers for centuries and is now a major culture system adapted worldwide. Scientific examination of the system has proven its superiority to monoculture in terms of ecological efficiency and environmental impacts. The eight-point management principles described below represent real farmer experiences and a wealth of knowledge; these principles remain applicable even today.

- 1) Water: clear, odourless, with good supply and drainage.
- 2) Seed: stocking large-size healthy fingerlings.
- 3) Feed: fresh, of high quality, palatable, digestible.
- 4) Control: feed fish on time at the same feeding spots with proper amount of quality feed; always pay attention to weather, water and fish.
- 5) Density: appropriate stocking density.
- 6) Multiple species: culture different species together with proper stocking ratio.
- 7) Rotation: undertake continuous stocking and partial harvest.
- 8) Prevention: good condition of water inlets and drainages; keep farm and ponds clean and free from contamination.

In such a system, new fish stockings can be done at virtually any time, taking into account the existing fish biomass in the pond. The partial harvest practices ensure that:

- harvested fish of multiple species have relatively large and unique size;
- fish supply to markets is homogeneous; and
- the pond has a relatively stable fish biomass.

Integrated farming systems evolved by Chinese farmers, particularly animal-fish integration, have had a remarkable impact globally, but particularly on poor and vulnerable farmers. It should be noted, for example, that rotational harvest, i.e. undertaking continuous stocking and harvesting, greatly improves fish yield as compared to single-harvest procedures.

It is important to note that Chinese aquaculture is gradually moving into a feed-based monoculture intensive system, largely focussed on one or two species. While the sustainability of these market-driven interventions would be based on market economics, integrated systems will continue to provide economic advantage to poor rural and urban fish farmers. Regarding future trends and major constraints, improving fish safety and the efficiency of integrated systems should be among the main foci through appropriate and field-based scientific interventions.

Aquaculture in China is now moving towards increased systems and species diversity, as well as increased productivity (Edwards 2008a, 2009d). Apart from modern monoculture, such as intensive shrimp culture, aquaculture systems in China vary in terms of inputs and management, and change greatly due to geographic and weather conditions. Farmers in China are extremely flexible and adaptive to their own natural, social and economic conditions and continuously modify their aquaculture systems to suit local conditions, using their own field-based knowledge. Research results are often at the background, and farmers' application of these results is blended with their own ideas. The excellent partnership between farmers and researchers in this country has favoured the rapid uptake of research outputs by farmers, who adapt new technologies

to local conditions. The entrepreneurial nature of Chinese farmers, aimed at meeting the increasing demand for aquatic food, has contributed to the rapid development of culture techniques. For each farming strategy and for each species being cultured in China, there are several innovations which could be described and documented in detail.

Carp culture innovations in Andhra Pradesh, India

Farmers in Andhra Pradesh have revolutionized carp culture by introducing it in rice production areas. Path-breaking farmers' innovations in terms of practices related to seed production and feeding strategies in Andhra Pradesh have been documented by many authors (e.g. Nandeesh, 2007; Ramakrishna, 2007; Edwards, 2008b; Roy, Saha and Kumaraiah, 2008). Carp culture was introduced around 1976 in Andhra Pradesh and expanded rapidly and intensified between 1985 and 2005. At present, the commercial culture of Indian major carps is undertaken by farmers in an area of about 90 000 ha, with all production being carried out in earthen dug-out ponds. As previously mentioned, many of the innovations related to feeding and culture practices have been documented in detail, including the most recent innovations of farmers regarding the use of much larger-size seed for early culture systems. The most significant innovations are related to species composition and polyculture strategies; these involve the culture of three commercially important species, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal carp (*Cirrhinus cirrhosus*), instead of the six species that have been normally recommended for polyculture by researchers. Another relevant innovation and improvement has been the change of stocking rate for species like *Labeo rohita* increasing it up to 90 percent of inclusion level, in view of its market demand. Also, instead of using small-size seed, farmers have developed the technique of using stunted seed that are aged but have not attained a weight proportionate to their age, and stimulating their rapid growth in a limited period of time by compensatory growth effect.

Regarding feeding strategies, farmers have developed a simple feeding method called “the bag feeding technique” whereby the feed is kept in feed bags with small perforations that may be arranged in two to three rows. Indian major carps have the habit of browsing, sucking the feed through perforations. Just by using these simple adaptations – flushing stunted seed, fertilizing ponds to produce an adequate amount of natural food and feeding through feed bags – farmers reached an average production of 8 tonnes/ha/year, with a maximum production of up to 15 tonnes/ha/year.

In order to reduce the culture period and increase the number of crops per year, farmers are now stunting the seed for more than one year and then fattening them to 200–300 g before stocking into the earthen culture ponds. Commercial culture of these fish is called “zero point culture”, the name being derived from the fact that the stocked fish have not attained 1 kg weight prior to stocking. These fish would attain a 1 kg weight in 5–8 months, depending on the density

and the resources used. Farmers have also developed innovative transportation and distribution systems for the movement of these large fish, since there is a separate group of farmers who have specialized in producing and distributing zero-point stock size fish. Farmers have used the available water storage tanks of 1–2 tonne capacity to stock fish and transport them by using continuous oxygenation.

With nearly 90 000 ha devoted to carp culture, a production of over 0.7 million tonnes, and considering that there is a limited consumption of fish in the state, farmers have developed cost-effective transportation, packing and distribution systems to transport marketable fish to other regions of the country, which reflects the innovative potential of farmers at each stage of the value chain.

A meticulous distribution and cost-efficient planning mechanism, based on their own research, has been developed in order to supply fish, based on orders. The entire production cycle is structured around the market demand. In the beginning, farmers used bamboo baskets for packing and transporting, but later switched to plastic trays; nowadays, plastic trays with insulated trucks are used to transport fish, not only to different parts of the country but also to other countries in the region such as Bangladesh and Nepal (Ramakrishna, 2010).

Freshwater prawn culture innovations in Bangladesh – technology transfer through a farmer field school approach

Bangladesh, a very densely populated country with serious problems pertaining to food security and nutrition, as well as poverty, has been focussing on a more efficient and sustainable use of its available and limited natural resources, such as water, land, feeds and seed, in order to improve the general food security situation and increase and diversify income-generating activities. There have been many relevant innovations made by fish farmers all over the country; these have already transformed the sector, and the country is recognized for its accomplishments with regard to efficient and diversified aquaculture production. In southwestern areas of Bangladesh, floods and droughts have been common problems, and farmers have been looking for alternative crops to rice, in order to improve and secure their income. A few years ago, a very innovative and progressive farmer of this region started to integrate rice production with giant river prawn, *Macrobrachium rosenbergii*, culture in unproductive paddy fields. This system evolved and was adopted successfully by many farmers within the same region. The system, popularly known as *gher*, has transformed the lives of several thousands of families, providing them with a very high and stable income through prawn cultivation. In the *gher* system, a canal is dug all around the paddy field, comprising 40–50 percent of the area, and the central portion is left undisturbed to undertake paddy cultivation. The soil excavated for the canal is used to make large dykes, in order to prevent flooding problems.

The major bottleneck nowadays is the availability of freshwater prawn seed, which is mostly collected from the wild; availability of seed spurred the rapid development of prawn farming, and there are several thousand farmers engaged in collecting postlarvae from natural waters. Few hatcheries have been established to cater to the seed requirement, and it is reported that wild-collected seed continue to be preferred by farmers (Nandeesh, 2003; Ahmed *et al.*, 2007; Ahmed and Troell, 2010).

Postlarvae are stocked in the canal and are nursed to the juvenile stage in pockets created in the canal by erecting small dykes. With the onset of monsoon, when the water fills the canal, postlarvae are spread to the entire area. In the past, farmers cultivated only one crop of paddy during the dry season, under the assumption that cultivation of paddy during the monsoon would negatively impact the growth of prawn; even in places where there was a potential, farmers did not cultivate a second crop. At present, with the educational programs provided to farmers, more than one crop of paddy is grown by good number of farmers.

The stocked prawns are fed largely with snail meat, in view of its ready availability in the area and its easy acceptance by prawns. Prawns are reared for a period of six months, and are harvested based on the average size and sold to processors. Total production ranges from 200–500 kg/ha. Thanks to the high price of prawn in the market, farmers have been able to earn good incomes, even with this small production.

The technology spread very rapidly in view of the good financial benefits farmers can derive by culturing prawn, which has high demand from the processing industry for export. However, due to inadequate technical support to farmers in planning their activities, some farmers ended up losing money and in some cases, total crop failure occurred with a disastrous consequence for the family.

Several non-governmental organizations (NGOs) have now stepped into this specific sector, providing technical support to farmers with the aim of defining their activities in a more sustainable way. CARE Bangladesh undertook a relevant project aimed at organizing farmers into clusters and empowering them with knowledge and skills by using a farmer field school approach. By adopting this experimental and field-based learning strategy, farmers were assisted to make good production plans that included stocking the proper number of postlarvae, raising them to juvenile stage by giving quality feed, raising these juveniles to market size by using homemade feed instead of using only snail meat, raising two crops of paddy comprising a dry season crop followed by a wet season one, using the large amount of available dyke space for cultivating vegetables, making financial plans to ensure adequate profitability and involving women in the entire crop cultivation process.

By adopting several of the practices mentioned above, farmers were able to improve prawn production substantially and earn additional income from the growing of vegetables in the dyke space. This integrated approach assisted several thousand families in substantially improving their incomes. This technology, which evolved in the southwestern part of Bangladesh, has now spread to other parts of the country, where farmers are now cultivating prawns along with rice and obtaining substantial income. It is reported that farmers who were earning only about USD80–100 by cultivating only rice are now able to earn over USD500 by adopting this integrated approach. With the establishment of several hatcheries devoted to the production of freshwater prawn seed, the use of hatchery-produced seed is gaining gradual prominence. The establishment of a very functional network for harvesting and distributing prawns in good conditions, either for marketing or processing, has helped farmers to continue the activity in a more sustainable and efficient way. The impact of this innovative technology has been very high and has contributed immensely to poverty alleviation. It is reported that Bangladesh is exporting 23 000 tonnes of freshwater prawn nowadays, which is around 11 percent of the global trade of this species (Ahmed, 2010).

Innovations in pangasiid culture in Viet Nam

The technology for the culture of pangasiid catfishes was initiated by the farmers in the lower Mekong region, particularly in Viet Nam and Cambodia. Among the 18 species, two species were and are widely cultured: “basa” (*Pangasius bocourti*) and “tra” or striped catfish (*Pangasianodon hypopthalmus*). The culture of these fish in ponds and cages has provided employment and improved food security to several thousand people (Nandeeshia *et al.*, 1997; Phuong and Oanh, 2010). While the culture of *P. bocourti* is limited, striped catfish culture is widely practiced by farmers. In the past, farmers used to collect wild-caught seed from the Mekong River, culturing them to marketable size in ponds or cages by feeding mostly with small fresh fish during the rainy seasons and dried fish mixed with rice bran during rest of the year.

In Cambodia, farmers culture striped catfish and have been able to obtain a production of up to 100 tonnes/ha/year. Seed are stocked at 5–6 fish/m² and are fed with cooked rice bran mixed with 10–15 percent dry fish during most of the year. However, during the fishing season, when fresh fish is available in abundance for two to three months, farmers feed them with small fresh fish or low-value fish as the main feed. With negligible amount of water exchange, farmers have been able to obtain production ranging from 40–100 tonnes/ha/year, based on the level of management strategies adopted.

Efficient and feasible breeding strategies, in combination with appropriate larval rearing techniques for striped catfish, developed by Vietnamese scientists in partnership with French and Norwegian collaborators, have led to a huge development of both the seed and table fish production industries. Currently, good amount of seed are easily available throughout the region. Related

farmers' innovations regarding culture practices in general, such as stocking densities, feeding strategies and rates, pond preparation and maintenance, harvesting, fish processing, fish distribution and exports have also led to a rapid and extremely efficient development of the sector. Vietnamese farmers are currently exporting large amounts of striped catfish to western markets. Through these export opportunities, farmers in Viet Nam have developed a very intensive production system by using ponds of 3–5 m depth and by stocking at a rate of around 20–30 fish/m³. Due to the high cost of land in the delta area, farmers have made use of the air-breathing physiology of the fish in order to intensify the culture by increasing the density based on the volume of water in deeper ponds, coupled with regular exchange of water. This has helped farmers to produce a higher volume of fish within the same pond area, by stocking based on the entire volume of water available in the pond.

Through adequate water exchange practices, farmers have been able to produce fish that meet the quality requirements of the processing sector, producing high-value-added products to meet the export market demand. Stocking of fish based on the total volume of water available in the pond is a major innovation made by farmers along the Vietnamese Mekong Delta area. Further, farmers have developed knowledge of the volume of water to be exchanged to produce quality fish. While some farmers still use homemade feed, the availability of quality floating feed has helped farmers to improve productivity by increasing the stocking density and feeding rate. All these factors have helped farmers to obtain an average yield of 400 tonnes/ha/crop for a rearing period of 6–7 months (Phuong and Onah, 2010). The processing sector has also been very innovative in terms of value-added product diversity and has diversified the export market to include nearly 80 countries.

However, the industry is also facing many challenges due to this intensive intensification process, such as increased disease incidence and outbreaks, as well as increasing feed costs. As the investment cost per hectare increases, the risk that small farmers have to face is very high. Although net return per hectare is reported to be high as compared to other species, farmers face great difficulty in carrying out this activity in a sustainable manner.

Among major challenges and future constraints, this fast-developed industry requires urgent scientific intervention in strong partnership with farmers to address the major challenges encountered. These include:

- *the declining quality of the available seed* – This is one of the major constraints reported by farmers. Hatcheries have taken up seed production and produce seed to meet the demand, but without any concern for quality. Appropriate broodstock management practices are lacking and inbreeding is a major limitation; brooders are repeatedly used for seed production during a season, and there is no exchange of brood stock on a regular basis with the wild-caught brood fish;

- *the increasing cost of feed* – This is a major concern, with more than 60 percent of production cost being attributed to feed. Producing quality feed at an affordable cost by using adequate feed formulations requires scientific interventions applying farmers' field knowledge; and
- *the huge gap between the farm gate price and the consumer retail price in various countries* – Reducing the difference would require market innovations and policy support.

The government has been quite proactive in supporting the Vietnamese catfish production industry by providing an appropriate legal framework, adequate policies and other enabling supporting structures. As the government has placed heavy emphasis on earning foreign exchange through exports, special support facilities for the production, processing and export sectors have been also provided.

The National Research Centre and Can Tho University, located in the Mekong Delta region, have not only acknowledged the farmers' innovativeness, but have also provided support to improve technology and disseminate farmers' innovations by establishing partnerships with entrepreneurial farmers. The government has also been providing research support through the national institutions to carry out technical studies on various issues. The Network of Aquaculture Centres in Asia- Pacific (NACA), an intergovernmental organization, has initiated a major programme to support farmers in developing better management practices (BMPs) through farmer participatory research.

Farmers have reached a point where further progress and sustainability will largely depend on the quality of scientific input. With the commercialization of the activity, there are challenges to carrying out on-farm research with farmers, but these are addressed in the process of developing BMPs. The success accomplished in Viet Nam has not been replicated elsewhere, and it is unlikely that such a level of production would become possible without adequate water availability. However, the species is gaining importance in countries such as Indonesia, Cambodia, India and Myanmar, with the aim of meeting domestic market demand and exploring new options

Seed production innovations in Cambodia

Cambodia has witnessed rapid growth in aquaculture in the past decade. The Tonle Sap Great Lake, which is known as a geographical wonder for its ability to become filled in the monsoon and emptied during the dry season, with an area fluctuating from 3 000 to 10 000 km², is the major location for aquaculture and capture fisheries production in the country. People living around the great lake are known to consume some 70 kg of fish/person/year. Rice-field fisheries and aquaculture systems, as well as fisheries activities in the Mekong River and its tributaries, also contribute to the fisheries sector in the region. However, with the Cambodian population increasing at a rate of 3 percent per year and

capture fisheries declining rapidly, it is predicted that the availability of fish per capita will decline if adequate steps are not taken to promote village-based fish culture systems. Recognizing this need, governmental agencies and NGOs have initiated programmes to promote fish culture since the 1990s. Where these programmes have focused on the promotion and development of small-scale aquaculture, they have demonstrated the rapid acceptance of the activity and the active participation of farmers in generating technologies adapted to their own local circumstances. Farmers have made innumerable innovations in Cambodia during these years, for example, with regard to feed production and feeding and fertilization strategies by using locally available raw materials and resources, such as terrestrial worms, aquatic macrophytes and snails as alternative protein sources. Farmers have been able to reach productions of up to 4 000 kg/ha/year in some locations, just by innovating and adapting small-scale aquaculture technologies developed in other regions of the world to suit their own needs and environment.

Major innovations have taken place regarding seed production and distribution, since the availability of good quality seed was one of the major constraints for aquaculture development in isolated and vulnerable areas. In order to sustain aquaculture development, decentralized seed production activities were initiated from the early stages of these previously mentioned projects. Innovations made by farmers in developing small-scale seed production technologies using local materials and traditional knowledge to establish classical Chinese-style hatcheries for floating eggs clearly demonstrate the innovative capacity of farmers when resources are extremely limited. Farmers, after learning the principles of Chinese hatchery operations, designed least-cost production units by using plastic sheets to line excavated earthen ponds in order to simulate the spawning area of the Chinese hatchery. Such earthen Chinese hatcheries have been successfully used for breeding and hatching for years, and with a great success in many locations. In most cases, thanks to the income generated from seed sales, producers have improved the hatcheries by using more durable materials.

Several designs of these Chinese hatcheries have been successfully built by farmers in different parts of the country (Nandeesh, 2002a, 2007; De Labra, 2008). They have been able to breed most of the cultivated carps, silver barb (*Barbonymus gonionotus*), catfish and even freshwater prawn. At present, it is estimated that over 100 hatcheries are operating in different parts of the country to meet the seed requirement of the farmers.

Aquaculture development in the northern provinces of Cambodia

The northern provinces of Cambodia, comprising Ratanakiri, Mondulakiri, Stung Treng and Kratie, are extremely isolated and mainly inhabited by indigenous people from a broad range of ethnic groups. Although these provinces are rich in natural resources, poverty and food insecurity are more acute than in the rest of

the country, mostly due to low agricultural productivity and the inefficient use of natural resources. Rural households located far from the Mekong River and its tributaries face real problems related to a low intake of high-quality protein and poor nutrition. Recently, these provinces have been targeted by several Spanish agencies in order to promote and develop small-scale aquaculture practices by improving and disseminating existing indigenous knowledge and practices, such as periphyton-based fish culture techniques in earthen ponds, community fish pond management and early larval rearing in small waterbodies. Interestingly, the response by farmers to improving their traditional techniques and adapting them to current local conditions has been very strong; fish farmers have become extremely implicated and motivated to grow fish successfully. Since the beginning of the programme, innovative dissemination strategies have been adopted in order to involve ethnic groups in the decision and learning processes. Through the innovative extension strategies adopted, farmers have been successful in obtaining good production using local resources available on the farm; rice-fish culture technologies have been well received by the farmers. As these provinces are located far away from the active seed production provinces, small-scale seed production technology has also been introduced in this area. Farmers have successfully adapted Chinese hatchery systems for floating eggs to meet the local demand; currently, most of the seed needed to assure a sustainable production has been produced in these small local private-scale hatcheries (De Labra, 2008).

Carp culture innovations in Myanmar

Myanmar has emerged as a major carp producing country in Asia. Several thousand hectares of carp farms have been established in the country, and it is reported that over USD80 million was made through the export of carps in 2008. The carp culture development in Myanmar resembles the situation prevailing in India, in terms of major innovations. Farmers in Myanmar have also evolved the existing technology for *labeo roho* culture (as the dominant species), and obtain a production of around 8 tonnes/ha/year. Stunted seed of 8–12 months and a weight of 50–100 g are stocked into large-size ponds and locally made supplementary feed applied. Unlike in Andhra Pradesh, where fertilization with both organic manures and inorganic fertilizers is used heavily, in Myanmar, supplemental homemade feeds and artificial feeds play a major role. Fish are stocked at 8 000–10 000 individuals/ha and grown for a period of one year. Fish are fed with rice bran and oil cake mixture, which has become very popular during these last years. Fish are harvested after they attain a weight of over 1 kg and then sent to market. These fish are either packed on ice and sent to Bangladesh for sale or processed by degutting and freezing, and exported to various countries, mainly in the Middle East (Ng, Soe and Phone, 2007).

Most of the seed supply required to maintain the sector is produced within the country, and efforts have been made to improve the genetic quality of fish through selective breeding programmes. For example, a pink-colour strain of

labeo roho has been developed which seems to have higher growth rate, better flesh quality and a desirable appearance. Although farmers have not been able to achieve good survival rates at the hatchery and nursery stages, they have been successful in producing at least the minimum required amount of seed to meet the country's demands.

Farmers' innovation in the culture of catfish, tilapia and shrimp in Thailand

Thailand has rapidly emerged as a major aquaculture-producing country thanks to the innovative nature of its farmers, combined with their entrepreneurial approach. In the freshwater aquaculture sector, there have been many farmers' innovations regarding the culture of catfish (*Clarias batrachus*), as well as the culture of hybrid catfish (*C. macrocephalus* x *C. gariepinus*). The efficient use of selected males of North African catfish (*Clarias gariepinus*) for artificial breeding and egg fertilization has been a real constraint for many years, and due to this reason, Thailand's farmers have developed a more sophisticated method whereby sperm is partially collected through an easy "surgery" procedure, after which males are released and can be used again for several times, after adequate recovery. This simple "surgical" method has become very popular in all regions of the country, and farmers have been able to save money, develop adequate selective breeding programmes at a small scale and improve operational efficiency (D. Little, unpublished).

Tilapia production in Thailand has increased notably in the past years, due to the innovations developed by farmers regarding seed production and distribution, through the establishment of quite successful seed producers' networks and clusters all over the country (Little, Kaewpaitoon and Haitook, 1994; Little *et al.*, 2007). These seed producers' networks exchange experiences and information between farmers and improve technology transfer. Thanks to establishment of these clusters and the successful exchange of information, a number of innovations have been made to hatchery and nursery management practices and technologies in order to improve operational efficiency (Bhujel, 2008). In both tilapia pond and cage culture, farmers have also adapted technologies from other regions of the world to their own local conditions in order to remain economically viable.

Regarding the culture of whiteleg shrimp (*Litopenaeus vannamei*) in Thailand, there is an innovative farmer, Mr. Banchong, who has built a hatchery close to Bangkok, about 60 km from the sea. He is has been using a very efficient and environmentally friendly recirculating system for more than eight years, involving water filtration, extraction of undesirable nutrients by using aquatic macrophytes in a treatment plant (reducing biological oxygen demand (BOD) and reusing treated filtered water for hatchery purposes. This farmer is also using the sea water to produce *Artemia* nauplii for use as live feed by using good-quality brooders collected from the field. Through the implementation of appropriate

biosecurity measures, this farmer is producing around 600 million nauplii/month. By using a recirculating water system, he is reported not only to be preventing disease outbreaks and major biosecurity constraints, but also to be saving the huge cost on water transportation (Kongkeo, New and Sukumasavin, 2008).

Farmers' innovation in freshwater and marine finfish larval rearing in Indonesia

Indonesia is another country that has registered rapid growth in aquaculture and has made breakthroughs in the breeding and larval rearing of several freshwater and marine finfish. Farmers in Indonesia are reported to obtain over 50 percent survival in the larval rearing of striped catfish, while it is still low in the Mekong region. By adopting effective feeding strategies and regimes to prevent cannibalism in the early stages, farmers have succeeded in achieving higher survival rates. The rapid development of the seed production industry for tilapia and common carp (*Cyprinus carpio*) has contributed to the rapid growth of the aquaculture sector as a whole (Edwards 2009a,b,c, 2010a,c,d).

Regarding marine finfish larval rearing technologies, farmers have been successful in establishing backyard hatchery systems. By using these facilities, farmers have been able to procure sufficient eggs and fry, and rear them until they are able to reach marketable size. In the case of milkfish (*Chanos chanos*), the Gondol research station recommended a set of facilities and practices in order to achieve adequate results in larval rearing, such as use of larval tanks, tanks for the culture of phytoplankton (*Nannochloropsis oculata*) and rotifers covered with appropriate roofs, feeding of larvae with rotifers followed by artificial feed, and rearing the larvae for 21 days. Once the farmers started the culture operation, they modified the technology to reduce costs by culturing larvae and plankton without any roof. Furthermore, some farmers started culturing rotifers by using trash fish, so that no artificial feed was required. By adopting this modified technology, the larval technology described with economics by Sugama, Saidah and Sunaryanto, 2006 has been modified and rearing period has been reduced to 15–16 days, instead of 21 days.).

Another example is the success achieved by farmers in Indonesia regarding the breeding of humpback grouper (*Cromileptes altivelis*) and brown-marbled grouper (*Epinephelus fuscoguttatus*) in order to increase the production of these highly demanded species (many farms in the country depend on the culture of these high-value species). Larval rearing of these species poses many challenges. While research stations advocated the use of artificial feed during larval rearing, farmers started to successfully use small shrimp and available low-value and trash fish. Furthermore, they started culturing the larvae in earthen ponds instead of concrete ponds or hapas, and this new system enhanced surprisingly both survival rates and growth. These successful adaptations made by farmers have contributed to the increased availability of larvae for culture.

Catfish culture and market-driven approach innovations in Nigeria

Fish is an important component of the diet of many Nigerians. With fish imports making up more than half of the supply, the Nigerian Government seeks import substitution through different programmes targeting increased domestic fish production, particularly through aquaculture promotion and development. The Nigerian experience involves several key innovations that launched commercial and market-driven fish farming within the country.

There are 15 hatcheries supplying enough high-quality seed to fish farmers. Farmers' innovations focused on maintaining stock quality and fingerling supply to market-oriented growers have triggered the growth of the sector, including the privatized extension support system. There are over 100 innovative farms that produce fish efficiently using high-quality seed of known origin, considering growth rates, flesh quality, disease resistance and high stocking density tolerance, among other traits. Technical support services provided by several private, public and semiprivate professional organizations such as the Fishery Society of Nigeria (FISON), the Catfish Farmers Association (CAFAN) and the Federal Department of Fisheries (FDF) have stimulated the healthy growth of the industry, and most farms are already integrated with seed and feed producers within a broad holistic approach. Given the availability of high-quality seed and feeds and the use of appropriate strategies for dissemination of proven technology, the aquaculture sector is expected to develop as a long-term, sustainable food-producing sector within the country.

Aquaculture development and farmers' innovations in Uganda

Ugandan aquaculture has seen a revolution, moving from an annual production of 285 tonnes in the early 1990s to 72 800 tonnes in 2008. Although the majority of fish farmers remain smallholder practitioners, the goal for aquaculture has changed, and this has led aquaculture to become a key production enterprise in Uganda, with an incredible annual growth rate of nearly 300 percent over the last ten years. Aquaculture production has quickly evolved and expanded to include not only small-scale fish farmers but also medium-scale farmers producing purely for external consumption through effective marketing.

A change in government policy in 2001 to move aquaculture from a livelihood approach to a market-driven strategy has changed the growth pattern of aquaculture. As the first step to provide quality seed, commercial hatcheries were encouraged to develop appropriate breeding and feeding strategies and coherent and well-implemented holistic biosecurity protocols highly adapted to the Ugandan context. Further, from a strictly pond-based system, aquaculture was moved to other innovative approaches, taking into account the specificities of the country in terms of the availability of water, land and other inputs; traditional agrolivestock practices, etc. During the last few years, innovative farming systems have been developed to increase efficient production; these include cage, pen and recirculating systems. The establishment of aquafeed

factories within the country, using adequate diet formulations and available raw materials has been essential to promote the industry and has strongly facilitated the healthy growth of the sector. Most importantly, capacity building of extension staff at the public, private and semipublic levels and institutional strengthening to promote farmers' learning through on-farm discovery, validation and analysis has helped the aquaculture sector to grow by making information and technology available to farmers in isolated areas. Skilled workers are essential for the promotion of new activities such as aquaculture. Through support to farmers, local development partners and the government, donor agencies have played an important catalytic role for aquaculture development through innovations since the beginning of the sector.

Australian freshwater crayfish culture innovations in Ecuador and Mexico

The culture of the Australian freshwater crayfish or redclaw (*Cherax quadricarinatus*) provides a good example demonstrating the innovative potential of farmers. Although still a small industry in Australia and several Latin American countries, redclaw culture was originally developed from farmer to farmer technology transfer.

Culture was initially developed in small-scale family operations as a hobby or for personal consumption. The relative ease of extensive production in large dams or man-made lakes encouraged some investors to attempt commercial production. A few farms became suppliers of juveniles for new farmers. These farmers would provide information of "best-known practices" through monthly newsletters. As a result, this cottage industry grew, with a reported production of 60 tonnes/year during the 1980s.

Due to the cannibalistic nature of the species, the development of culture techniques based on refuges or "hiding places" was necessary. Farmers in Australia found that old, discarded car tires could be obtained at no cost, so they used them to provide refuges for redclaw. This allowed for a more consistent survival in the ponds and yields of 1.5 tonnes/ha. In Ecuador, tires were not an option, as they are retreated and re-used, so local bamboo was cut to an adequate length and bundled together to provide hiding places. These bamboo bundles were easier to use, which helped improve yields (2 500 kg/ha), reduce manpower needed to set a culture pond, and facilitated drainage and pond cleanup. Nevertheless, bamboo tended to rot after two or three production years, thus creating a medium-term problem. For this reason, farmers began using cement bricks as hiding places. These allowed for consistent pond set-up, eliminated the impact of decomposing bamboo in the pond (which helped yields), and reduced total organic matter in drain water, thus reducing the impact on the environment.

Farmer innovation on the original production technology is also evident in terms of juvenile production. Farmers in Australia developed the use of onion-bag

bundles to protect small juveniles in the ponds from cannibalism and to harvest them from ponds. In Ecuador and Mexico, the systematic use of onion-bag bundles allowed farmers to harvest juveniles and select for size more efficiently, increasing yield and reducing production cost per juvenile.

Similarly, the lack of basic knowledge on the nutritional requirements of the species did not prevent Australian farmers from cultivating the crayfish. Good growth rates were obtained by supplying them with a variety of locally available feedstuffs, such as boiled potatoes and carrots, pelletized barley and chicken-layer pellets. Daily observation even allowed farmers to realize that redclaw would actively seek several feedstuffs, such as boiled corn cobs, near the edge of the pond at night, which helped the farmer to determine size of the organism and the feeding demand and even allowed for the trapping of some examples for personal consumption or small volume sales.

Attention to species behaviour in the pond also helped farmers design more efficient harvesting methods, such as the flow trap, which works on the principle of counter-current freshwater attracting crayfish out from stagnated pond water. This allowed for systematic “self-harvesting” of the crayfish at night, thus reducing manpower requirements and limiting the impact of workers’ feet on the pond bottom and crayfish being stepped on by farmers during “hands-on” harvesting.

Indigenous species culture innovations in the Tabasco region, Mexico

Tabasco possesses one of the main wetlands in Mesoamerica, Reserve of the Biosphere, Pantanos de Centla, with 305 000 ha where the Grijalva and Usumacinta rivers come together, adding nutrients to associated estuaries, lagoons and coastal zones, helping important fisheries for fish (e.g. sharks, rays, snooks, red porgy, pompanos, mackerel, cutlass fish, gars, native cichlids), crustaceans (shrimp and river prawn) and bivalve molluscs (American cupped oyster, *Crasostrea virginica*). Capture fishery is thus the primary activity of the rural populations living in proximity to these ecosystems, due to its relative ease and low production costs.

However, aquaculture production and research on the culture of native species are being actively promoted as an alternative to capture fisheries. The native species being cultured following innovative approaches are: tropical gar (*Atractosteus tropicus*), bay snook (*Petenia splendida*), Mexican mojarra (*Cichlasoma urophthalmum*) and common snook (*Centropomus undecimalis*). Studies on tropical gar have placed this specific research group on the international forefront with regard to the generation of basic knowledge applicable to biological conservation, culture technologies for meat production, and the production of ornamental fish by aquaculture.

Efforts have been made to develop culture technology for the native species using many of the rustic ponds available in rural areas. Scientists from the Tropical Aquaculture Laboratory have provided the technical support to stimulate farmers' involvement in developing technologies through adaptive research. Using a market approach, an exploratory study was conducted to examine the four characteristics of tropical gar consumption in the Tabasco region, namely (i) economic importance, (ii) presentation, (iii) quality and (iv) traceability. The study was implemented in 50 restaurants. The most important results show that tropical gar represents an average of 10 percent of total sales, that its availability is seasonal, and that it is consumed mainly in grilled form. The results indicate that tropical gar has an important nutritional, economic and cultural value in Tabasco. This type of exploratory study can be used to evaluate consumption of other native species and understand the market requirements, and based on such studies, technological interventions could be planned to develop an efficient and sustainable tropical gar industry.

40 years of innovations in shrimp culture in Mexico

The shrimp culture industry in Mexico has generated many adaptations and innovations by farmers in order to develop the best breeding and farming practices. The legal framework developed by the government has enabled a coherent and regulated growth of the industry, maintaining its long-term sustainability and even overcoming most of the challenges posed by the shrimp farming sector at the social, economic and environmental levels.

Although the industry started collecting seed from the wild, by the year 2 000 there were practically no farms using wild-caught larvae for aquaculture purposes. The last decade witnessed the development of hatcheries with strict biosecurity protocols to ensure healthy seed production; thanks to this approach, the sector has become wide-spread.

Although initially blue shrimp (*L. stylirostris*) were used, whiteleg shrimp (*L. vannamei*) is the most commonly cultured species, as it is adaptable, easy to breed and has higher tail yield.

Innovations made on pond design for effective filling and drainage of water and on pond shape to facilitate strategies for easy harvesting have contributed to increased production. An important progress was the construction of breakwaters and pumping stations out on the open sea. Almost without exception, farms collected their water from estuaries or coastal lagoons with low hydrodynamics, but this posed a limit to future expansion of the sector. Once free of these constraints, large land areas with coastline proximity were finally adapted to shrimp culture.

Further, feeding efficiency was increased in many ways through optimization of feeding strategies, such as an increase in the number of daily feedings to

four per day. To maintain better water quality, special aquaculture fertilizers and probiotics were used. Stocking densities were increased from 10–12 postlarvae/m² to 40 postlarvae/m², which is the optimal stocking density used today by many farms.

Innovations regarding indigenous species culture in Colombia

Aquaculture is growing rapidly in Colombia through the successful linkage of farmers and research institutions. Farmers are closely assisted by scientists through on-farm validation and appropriate dissemination technologies. The success achieved with the culture of Nile tilapia (*Oreochromis niloticus*) and red tilapia has prompted the farmers to explore the culture of these species integrated with other native species that are very popular in local markets, such as dorada (*Brycon moorei*), netted prochilod (*Prochilodus reticulatus*), cachama (*Colossoma macropomum*) and pirapatinga (*Piaractus brachipomus*). The joint initiative of the Outreach Station of Caldas University and farmers has led to a number of farmers' innovations. Some of the most relevant innovative strategies which have already made very significant impacts include: polyculture of tilapia with native species, development of greenhouse technologies to regulate temperature during the winter, development of aquafeeds using local raw materials and resources, development of sustainable fertilization technologies, supplemental feeding strategies, and the establishment of recirculation systems using hydraulic power.

The study's results clearly demonstrate that the involvement of the community and the research centers (in partnership) in the needs identification process within the aquaculture sector is extremely fruitful; planning and initiative development based on such identified needs will hasten the development process.

Dissemination of success stories – case studies

Information dissemination has been one of the major constraints which continues to hinder the development and the transfer of technology in many ways. However, with the introduction of new methodologies in the field of information technology, it is now possible to distribute and disseminate information globally in an affordable way to many developing countries. Information dissemination alone will not bring major benefits unless there are people with the necessary capacity to absorb the knowledge disseminated and build skills and transfer knowledge into practical benefits. In this section, examples are presented of how institutions and communications and dissemination tools have helped in transforming the aquaculture sector in the past decade.

Genetically improved farmed tilapia (GIFT) and its impact

The application of genetics tools in aquaculture is still very limited as compared to plant and livestock production. The WorldFish Center made a maiden effort to apply quantitative genetics principles to improve growth performance in farmed

tilapia. Although Mozambique tilapia (*Oreochromis mossambicus*) has been viewed negatively in most parts of Asia, the Nile tilapia (*O. niloticus*) is considered as a boon for both the poor and the rich, in view of its flesh quality and ability to grow in different environments. Since most of the countries cultivating this species were experiencing poor growth performance, mostly due to the small gene pool within the population that was used for seed production and culture, the WorldFish Center decided to undertake this major project with the support of the Asian Development Bank and in collaboration with other partners such as AKVAFORSK from Norway, in order to develop a genetically improved strain of tilapia. In this project, stocks were collected from four countries in Africa, namely Ghana, Senegal, Ivory Coast and Egypt, as well as from four Asian countries, i.e. the Philippines, Singapore, China and Thailand. These stocks were cross bred through family selection as well as within family selection. Twenty-five different base populations were used to evolve the best possible strain through a traditional quantitative selective breeding process.

The strain that was developed for years through this selective breeding process has been disseminated to a number of countries in Asia by following suitable guidelines and training procedures in order to prevent possible negative impacts on the environment and achieve the best results. The stocks have been introduced to Bangladesh, Ivory Coast, Egypt, Fiji, India, Indonesia, Kenya, Laos PDR, Malaysia, Papua New Guinea, China and Viet Nam, and they have been held in identified hatcheries in order to maintain their genetic purity and specific quality of the stock. In some of these countries, efforts have been made to improve these stocks further through the selective breeding process. Bangladesh is reported to have evolved an improved strain of tilapia which has been named as “super gift tilapia”. The selective breeding process has helped to improve the growth by 12–17 percent per generation.

In order to ensure continuity of the genetic improvement programme and the sustainability of the activity, WorldFish Center has transferred the project fish collections to the newly established GIFT Foundation Inc., which is a non-stock, non-profit corporation established by the institutional partners involved in the project. The foundation has made an effort to distribute GIFT tilapia to private hatcheries on a licensing basis. However, as the private hatcheries were reluctant to enter into an agreement involving legal documentation procedures, after two years of experience, agreement was made with a Norwegian private company, GenoMar ASA, to ensure wider distribution of the genetically improved stock through their established management structures.

The procedure demonstrated by this project in establishing responsible management of a certain genetic stock has contributed in many ways to the further improvement of new strains through country-specific breeding programmes. Such a success has been largely possible due to the well-planned scientific programme, which was focussed on dissemination of the strain

together with capacity building of the national staff charged with continuing the required breeding activities beyond the project phase. This project has contributed not only to food security but also to poverty alleviation, thanks to the high demand for the product in the global market (Acosta, Sevilleja and Gupta, 2006; Acosta and Gupta, 2010).

It is also important to note that the project envisaged building the capacities of various governments and institutions during the implementation period. This activity was introduced in the programme in order to support the original objectives of improving the performance of tilapia through a selective breeding process. In order to continue this capacity-building process, as well as sharing of information, the International Network on Genetics in Aquaculture (INGA) has been established, based in the WorldFish Center headquarters. Periodic meetings of INGA to share information and ideas through mutual consultation processes have brought benefits to the countries and individuals participating in the programme.

This project has contributed immensely, not only in providing an improved strain of tilapia, but also by stimulating research in the application of selective breeding methodologies to other species such as labeo roho and silver barb and to other strains of tilapia. The major lesson learnt through this project is that partnership research programmes involving developing and developed countries can bring great benefits to the people through the application of good science. Further, partnerships between research institutions and the private sector can stimulate rapid development and dissemination of technology. The project has also proven that investment in human resource development can bring sustainable benefits for the improvement of the aquaculture sector. The impact of this improved strain of tilapia has contributed to the dramatic increase in production in many countries of Asia.

Dissemination of sex-reversed tilapia technology developed by the Asian Institute of Technology

The Asian Institute of Technology (AIT) developed the technique of sex reversal for the production of all male tilapia production during the 1980s. For the dissemination of the technology, the institute established several partnerships with private hatcheries and also helped in spreading the technology of production of monosex tilapia by using 17-alpha methyl testosterone. The technology involves the rearing of quality broodstock and egg production with the appropriate male to female sex ratio. Fertilized eggs collected from the mouths of female tilapias are incubated with continuous flow of water. The hatched larvae are fed with artificial feed incorporated with the hormone for about 30 days. These sex-reversed all-male tilapia grow faster, and this is also a feasible way of avoiding the constraint of early maturation.

AIT's training unit undertook several initiatives to organize training and technology transfer to rural fish farmers all around the country on the production

of monosex tilapia and their culture in confined environments. As a result, the technology spread very rapidly in Thailand, where it has contributed to a major revolution in tilapia culture.

Well-planned research programmes coupled with a strong outreach programme made a major impact by addressing several of the problems encountered in the promotion of the technology. In addition, as part of the outreach programme, several training projects were organized on breeding and farming systems for tilapia, and these attracted the interest of various countries and agencies which have taken the opportunity to train their own personnel. In addition, a master's degree (M.Sc.) programme in aquaculture developed by AIT helped in producing well-trained manpower to address major problems faced at the field level in different countries. As a result of this sustained effort, tilapia breeding and sex-reversal technology has been spread to several countries in Asia with very good results, particularly in Bangladesh, Viet Nam, China and Malaysia.

Periodic short-term training courses organized by AIT on tilapia seed production and training technology have facilitated the development of manpower with the required skills and knowledge, not only in Asia but also in Africa and Latin America. The hands-on training, coupled with successful hatchery operations within the institute and with field training and research involving private hatcheries in Thailand have helped trainees to see the practical results of the programme and thus helped build their confidence in the technology. Since AIT has a successful M.Sc. programme in aquaculture that is mainly focused on Asia, it has been able to attract a good number of technicians from different Asian countries; such trained human resources have also facilitated the spread of the technology (Bhujel, 2008).

The lessons learnt from the AIT experience clearly demonstrate that well-founded education combined with practical training and supported by active research programmes could help in the spread of technology. Quality human resource development is the key for spreading appropriate technology.

Integrated Fish Farming Training Centre, Wuxi, China

China is not only the leader in aquaculture production, but has also led in disseminating knowledge and technology on aquaculture and fishery management during the last three decades. The Freshwater Fisheries Research Center (FFRC) in Wuxi has been organizing training for people from various countries for the past 30 years. The course and seminars were designed mainly to build the capacity of people from developing countries in aquaculture and fishery management. The training programme on integrated fish farming, which started as an FAO-United Nations Development Programme (UNDP) supported activity, focused on the integration of fish with other animals and farming systems, has attracted interest from many countries involved in aquaculture. In 1992, the training programme was taken over by the Government of China and is run as

an international programme supported with full funding by the government. The training programmes have now been diversified into both aquaculture and fishery management. To date, the center has attracted participants from 100 countries and more than 1 400 persons have been trained. While most participants were men (81 percent), the number of women trainees has clearly increased in recent years. NACA has been coordinating the selection of trainees from member countries and facilitated the travel and training during the early years. The hands-on training gives an opportunity for the participants to gain experience in aquaculture technologies such as pond construction, seed production, feed management, disease prevention, etc. The integration of fish with animals such as pigs, ducks and cattle and with plants such as paddy and mulberry has demonstrated sustainable models of resource utilization.

The Wuxi center was built with all the necessary facilities for training, research and extension activities, combined with good fish farms, hatcheries and successful integrated farming systems for field practices within the campus, as well as facilities close to the center that have made this programme highly successful (Anon., 2005; Bueno, 2005a,b). Alumni have made visible impacts in many countries by applying some of the good practices. The approach of China in spreading knowledge, even to the extent of covering all costs for participants from developing countries, is a noteworthy example for other countries to emulate.

The lesson learnt from this programme is that practical training on various aspects of fish seed production, integrated fish culture, feeding strategies and disease management, as well as sustainable and responsible approaches in natural resource management have enabled trainees to gain confidence in these activities and replicate them in their countries. Exchange on lessons and experiences on China's fishery and aquaculture development history would also help trainees and participants. Most importantly, trainings of this nature have helped participants to learn from each other, exchange experiences, ideas and technology, learning about the aquaculture practices prevalent in different regions of the world and the problems confronted in developing the culture systems. These trainings have helped to build strong linkages between trainees and the faculty of the FFRC and with the companies in the fishery industry. In addition, cultural linkages have been a major benefit.

Network of Aquaculture Centres in Asia-Pacific

The Network of Aquaculture Centres in Asia-Pacific (NACA), an intergovernmental institution created with the purpose of sharing information between countries in the Asia Pacific region, has proved to be one of the most successful experiments in the aquaculture world. In the past 25 years, NACA has taken up the role of bringing all its member countries to a regular platform to discuss the issues and develop strategies for aquaculture development through regional cooperation (Bueno, 2006a,b). Currently, there are 21 member countries and

the organization is managed by representatives from all members. The NACA Governing Council is chaired by a member country representative on an annual rotation, providing all the countries equal opportunity. A Technical Advisory Committee comprised of experts nominated from each country provides the necessary technical support on training, research, exchange visits, planning and implementation.

NACA's many accomplishments include information dissemination, well-planned and targeted training programmes, field-based strategic research programmes that address common problems encountered by member countries, and influencing policies through educating the right people. NACA's efforts to focus attention on the problems caused by fish and shellfish diseases through a number of training and research initiatives is a major contribution to the region. NACA serves as a regional nodal organization and has been working closely with FAO and a number of other donors in a wide range of activities, projects and programmes. Attempts have been made to create similar regional platforms to promote aquaculture development in various parts of the world, including Central Asia, Africa and Latin America. The positive lesson learned is that professionally managed organizations such as NACA can attract funding for various activities and bring benefits to people. The presence of NACA has been extremely helpful, not only to exchange expertise, but also to address emergency situations, particularly when calamities such as floods or epidemic diseases occur, as in the case of Asia after the tsunami of 2004.

"Aquaculture Asia", a quarterly magazine published by NACA and made available for free Internet download, has helped in information dissemination in many ways. Several of the innovations and farmer practices documented in the magazine have stimulated aquaculture development in many countries. The Website, with free access and download of specific and aquaculture-related publications, has become a popular site within the aquaculture community. Over the last few years, NACA has increased its impact on the science of aquaculture, basing its development strategies on the findings of scientific investigations that are open to public scrutiny and peer review.

National Centre for Sustainable Aquaculture

The success accomplished through the NACA-MPEDA (Marine Products Export Development Authority) project in India has helped the creation of a new institution called the National Centre for Sustainable Aquaculture (NaCSA) by MPEDA (Padiyar *et.al.*, 2003; Umesh, *et.al.* 2010). The institution was created in 2007, and has already made great impact in terms of promoting best management practices (BMPs) through a cluster approach. The activity has been expanded to cover six of the coastal states involved in shrimp farming in the country. The institution has established several farmers' welfare societies and has encouraged farmers to initiate aquaculture through a group-collaborative approach. These farmers have also been linked to international buyers. Because

of this direct linkage between the companies, the importing countries and the producers of the developing countries, they will be able to get higher market rates for the produce. So far, more than 750 societies involving 16 500 farmers have been established, and their produce will be sold directly to the SYSCO Corporation in the United States of America through an agreement to buy 10 000 tonnes of shrimp. The established group has helped to reduce disease incidence, increased productivity and quality, increased access to good-quality products, increased profit through reduced production costs, and improved market access through increased ability to meet market requirements such as organic certification, traceability and eco-friendly sustainable production. Revival of abandoned ponds, increased food security, improved livelihoods and empowerment of small-scale farmers to have a collective voice have been the significant outputs of this group approach. The institution that has been created has been able to make a great impact using contractual employees whose continuation is directly linked to their performance. This is the first experimentation that clearly reflects good success when an organization has well-defined programmes and performance assessments. NaCSA aims to reclaim most of the abandoned farms through organizing farmer groups and promoting aquaculture through the cluster approach. The lesson learnt is that shrimp can be grown with reduced disease problems provided sustainable BMPs are adopted through a cluster approach.

The implementation of BMPs through the cluster concept has provided benefits to the farmers, the environment and the local community. A summary of the project's impacts is given in Table 1.

There are many lessons to be learnt from the work of this project. Such lessons are not only useful in improving the processes with time but could have relevance and application to the development of small-scale practices. Examples include:

- Improved farm management practices can reduce environmental impacts, ensure food safety and improve farm profit. The “win-win” situation created by adoption of better management provides a strong incentive for positive change.
- Organization of small-scale aquaculture farmers brings about positive social and economic benefits to members. These benefits include:
 - Collective planning and shared responsibility help achieve better management of risks.
 - Cluster model of BMP implementation is developing into a self-propagating model (farmers believe farmers).
 - Farmer groups can have stronger negotiation power with the input suppliers and traders.
- The following points should be considered while organizing farmer groups:
 - Farmer groups comprise farmers with different needs, interests, skills and financial and technical capacity. A few common interests can hold them together in a group.

- To secure the confidence of farmers, provision of technical services should be independent and without conflict of interest.
- Investment in institutions (e.g. NaCSA) that are focused on small-scale farmers can facilitate formation of groups and adoption of BMPs.
- Revival of the shrimp sector is possible. Shrimp farming can be a source of sustainable livelihoods for small-scale farmers provided risks are managed through improved management and institution building.
- Experiences from India are widely applicable in other countries across the region.

By the end of 2012, NaCSA plans to organize 50 000 small-scale shrimp farmers into societies and help them sustain their livelihoods. It will help societies switch to sustainable energy resources for their routine farm operations and facilitate access to institutional finance and insurance. |By 2011, cluster certification is planned for about 100 societies and by 2013, all 2 000 societies should be certified. This will help the societies meet emerging market requirements and improve the market access for their produce. Empowered farmers can influence policy-making in their favour.

TABLE 1
Summary of the positive impacts of the National Centre for Sustainable Aquaculture

Risks	Positive impact	Remarks
Disease	– Reduced disease incidence	– 27% decrease in disease prevalence in BMP ponds compared to non-BMP ponds.
Food safety	– Reduced chemical & no antibiotic use	– All preharvest shrimp samples from society ponds tested negative for presence of antibiotics. – Complete traceability of the product.
Improving supply chain & market access	– Increased opportunity for market access	– Middlemen/agents eliminated at all levels of production, finance and marketing. – Plans are in progress to market society-produced shrimp to Sysco Corporation, USA for better price.
Financial	– Improved profits – Opportunity for bank credit access	– By reducing the cost of production, profits have been increased. Non-BMP ponds got INR39 (USD0.8) for every INR1 000 (USD20) spent, whereas BMP ponds got INR128 (USD2.6) for the same amount of investment during the 2009 harvest season.
Social	– Democratic & transparent societies – Increased communication – Sharing of costs – Development of local leadership	– Democratically organized farmer groups. – Regular information sharing among farmers. – Cooperation in selecting, testing and buying quality seed and other inputs. – Farmers share cost to build common infrastructure (electricity, laboratories, auction hall, etc.) – Organization of farmers into societies helps to develop local leadership. The most successful farmer societies have strong leaders who have vision and commitment, which is very important for society management and success.
Environmental	– Lower stocking densities – Reduced pollution – Increased environmental awareness	– Stocking density of society shrimp ponds (<10 shrimp/m ²) is far below that used in other countries. – Maximized efficient water use by reduced water exchange and minimized discharges. – Five societies have adopted organic aquaculture practices. – Abandoned shrimp ponds being revived.

Establishment of fish farmers' networks

Fish seed producers' networks, established largely in the private sector in many Asian countries, have contributed to aquaculture development in many ways and in many regions. Successful examples of these networks are seen in Bangladesh, India, Viet Nam, Lao PDR, Thailand and Cambodia (Little, Nietes-Satapornvanit and Barman, 2007). These networks assist in the effective distribution of proven and certified quality seed with a fixed price to areas that are generally not accessed by government extension workers or public hatcheries. The networks operate in different ways in different countries, based on the circumstances, labour availability, ease of transportation, etc. In Bangladesh, while the nursing operation is carried out by groups of farmers, a number of poor people are engaged in seed distribution. These seed distributors have also been used as message delivery agents, in view of their ability to reach various locations.

While the seed network system exists almost in a similar way in West Bengal, India, in Southeast Asia, these networks have proved to be successful in meeting the seed requirements of farmers by employing various communication mechanisms. In Thailand, with tilapia being a prominent culture species, establishment of these networks in northeastern areas have stimulated a good growth of the aquaculture sector.

Cambodia, which is emerging as a quite important country and organize within the aquaculture sector, also has a long history of seed producers' networks. The success in aquaculture has been largely due to seed production facilities being established in different parts of the country and the establishment of networks to address various issues related to seed production and distribution. As the number of seed producers has increased, with a view to create a platform for the exchange of information and develop strategies to ensure quality seed production, fish seed networks have been established in four provinces. The network members meet once a month to discuss various issues related to technology, management and marketing of fish seed, including fixation of prices for the fish seed to prevent undue competition. Annually, network members are brought together to present their experiences and discuss the strategies that are needed to ensure quality seed supply to farmers. These annual meetings also provide an opportunity for the members to present their problems collectively to government authorities. With the participation of various NGOs, donors and provincial authorities in such meetings, many of the management issues are resolved and plans are made to enable the farmers to continue their activities. The network has proved to be an effective platform for dissemination of information.

Productive linkages between farmers and scientists

There are several examples from Uganda of successful synergic approaches between farmers and researchers from both public agencies and NGOs. For instance, the National Agriculture Research System, where public research for

aquaculture falls explicitly, calls for on-farm or field-based research as the ideal research and outreach strategy. During recent years, these partnerships have promoted the use of three new indigenous fish species for aquaculture purposes and the improvement of fish feed, hatchery operations and management, and the handling, processing and marketing of farmed fish. Partnerships with farmers are a rule, not an exception for the Ugandan Government, with farmers involved right from deciding on the kind of research that has to be undertaken through the entire research process and programme.

A quite didactic example from Mexico is the collaborative approach between farmers and scientists from the Northwest Biological Research Center, in an attempt to bridge the innovation gap through BioHelis, its innovation and technology park. Over the last 20 years, this interaction has allowed for significant advances in aquaculture production. Based on more than 60 research papers and 20 theses relating to critical aspects of reproduction, nutrition and production, technology development has allowed commercial producers to obtain more than four times the number of juveniles per square meter in greenhouse systems without water exchange, and at cost reduction of up to 14 percent when compared with traditional techniques. On the other hand, intensive commercial grow out with 0 percent water exchange and controlled aeration allows for an increase of up to 73 percent on reported production rates, with a reduction of more than 20 percent in production costs. The technology reduces energy consumption, improves feed conversion rates, optimizes the use of water and significantly reduces the cost of production.

Examples of linkages between on-farm experiences in partnership with research institutions and public bodies in Mexico

After the appearance of white spot disease (WSD), the two main producers in Mexico, the states of Sinaloa and Sonora, (with a production of 80 to 90 percent of the national yield) have had varied performance. Sinaloa was the production leader for many years, and in the early 1990s it was responsible for 80 percent of all production, but now production has dropped to 30 percent. Sonora has displayed quite the opposite pattern: during the early 1990s it was responsible for 15 percent of the production volume, but in the last four years, it has generated 60 percent of the national shrimp production.

We will now see the process lived by the Sonoran farmers in their search for a healthy and pathogen-free environment. In 2001, the states of Sinaloa and Sonora began a new season of uncertainty: WSD appeared in different regions, sometimes devastating an entire zone, yet the neighbouring area remained safe. In order to control the situation, a group of farmers –under the banner of the Asociación de Acuicultores Privados del Estado de Sonora A.C. – developed a plan focused on aquaculture health. Research began by examining other similar fields such as vegetable, porcine and avian health, and the necessary paperwork was done before state and federal agencies, as well as before

the shrimp farmer's guild. As a result, on July 2002, the Comité de Sanidad Acuícola del Estado de Sonora (COSAES, the Aquaculture Health Committee of the State of Sonora) was created, and it was composed mainly of shrimp farmers. It was the first entity of its kind in Mexico, and some time later the other states created their own committees. These entities collaborate with governmental agencies such as the Comisión Nacional de Acuicultura y Pesca (CONAPESCA, the National Commission for Fisheries and Aquaculture) and the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA, the National Quality Service for Healthy and Innocuous Agrifoods), and its main objective is to promote the use of good sanitary practices in the management of shrimp farms.

Once COSAES was constituted, it proceeded to elaborate a sanitary protocol for the 2003 cycle under which all farms and hatcheries in the state would operate. Stocking and harvest permits – documents that are issued by this committee – were only given to farms that followed these sanitation protocols. By 2003, 95 percent of all farmers obtained their stocking and harvest permits. These positive results improved every year, and Sonora went from producing 18 000 tonnes of farm-raised shrimp in 2002 (the year of COSAES' inception) to 68 000 tonnes (higher than the national fisheries yield) in 2007, and this in a scenario of diminishing yields in all other regions.

Nonetheless, without the existence of a law or norm issued by either the state or federal governments to fully support the agreements settled under COSAES, there was never 100 percent compliance to its protocols, and thus emerges the necessity to elaborate an aquaculture law that will grant it the powers needed to exert full compliance and apply sanctions and fines to offenders. So the next step was the generation of a State of Sonora Aquaculture Law, issued in December 2005, and from this moment, all producers fully complied with the protocols. It is important to state that the juridical actions undertaken by Sonora were responsible for the creation of the Ley General de Pesca y Acuicultura Sustentables (the Sustainable Fisheries and Aquaculture Law), published on 24 August 2007. In order to conform to the federal law, the State of Sonora's law was modified and the Fisheries and Aquaculture Law of the State of Sonora was issued on 28 August 2008. Nowadays, Sonora is the only state with such a law, and this might be the main difference with the actions implemented in Sinaloa.

Use of information and communications technology (ICT) in the information dissemination process

Among the many different types of communication systems, electronic communication tools and mechanisms are extremely fast, feasible, easily accessible and affordable. Although there are still difficulties in many developing economies to access the Internet, the situation is improving rapidly with the participation of the private sector and specific government policy initiatives to ensure adequate communication linkages to remote areas.

Tilapia@yahoogroups.com

One of the successful networks is the tilapia group (tilapia@yahoogroups.com). The group started in 1999, has successfully completed 12 years and now has a membership exceeding 3 000 people. This group, started by Mr Tom Fresse of Aquasol Inc in Hawaii, is helping people from different countries and with different backgrounds to register as members and obtain the necessary information. It was started based on the fact that there are thousands of tilapia farmers all over the world who would benefit from such a global exchange of information specifically related to tilapia. As the mailing list comprises of all types of farmers operating small to large farms that are focused on domestic and commercial production, researchers, development professionals, etc., it not only provides a platform to share diverse experiences but also a very global overview of the reality of the sector. The group has been managed by Tom Fresse, with no cost involved, excepting his time and resources. On a daily basis, he spends about 15 minutes on average managing the list, but occasionally it can be several hours. Most of his time is spent on sending invitations and managing and editing the posts. There have been some problems encountered regarding language barriers, commercial posts, e-mail prospecting by people not interested in tilapia, flaming, personal messages, member removal requests and poor quality posts. To overcome these problems, mail moderation has been started. No attachments are allowed, but provision has been made to upload files where people can access them and download the information.

Although, moderation is viewed differently by different people, without moderation, maintaining such a large group with diverse interests would not be possible. Furthermore, unnecessary and unrelated mail delivery can contribute to loss of members, as the increased mail can cause loss of time. Moderation has proved to be effective in improving quality and regulate mail traffic. Many professionals have been invited to join the group. Their advice and unselfish service have helped maintain the quality. It is really the quality of the posts that makes the difference. Based on the experience of 12 years, Tom's advice to others wishing to start a group is to go for it! It's not hard and once it is set up and running with a reasonable membership count in place, the group will quickly have word-of-mouth positive feedback, and you will see membership rise with little or no effort. One of the most fascinating experiences about the list is learning how different countries operate their tilapia farming industries; such a global platform provides opportunity to learn from each other's experience.

Sustainable Aquaculture Research Networks for Sub Saharan Africa (SARNISSA)

SARNISSA is a network created to improve access to information through individuals in sub-Saharan Africa (SSA) and beyond. This project was supported by the European Union, in collaboration with institutions from Africa, Asia and Europe, and with the Institute of Aquaculture, University of Stirling as the lead center. This project, with more than three years of existence, already has large number

very active members from all parts of the world, majority representing all major institutions and organizations in Africa. Effective dissemination of information using both English and French is much appreciated by all the members. The principle objective of SARNISSA is to strengthen the capacity of African researchers and development professionals by enabling them to have access to information. In addition to the e-mail group, there is also a Website which serves as a repository for various information. With the support ending from European Union, efforts are on to find ways to sustain the activities and members themselves have been actively involved in finding ways to continue this platform.

Other successful methods

In countries like Thailand, print media are often preferred by farmers, and much of the extension material on various cultured species is produced by the Thai Department of Fisheries as hard copy. In China, television channels dedicated to agricultural activities appear to be a popular means for farmers to receive new information. In Bangladesh, folk art is used as a medium to convey important messages. Providing information to farmers in their preferred manner is essential to having a maximum impact.

Emerging issues

Factors that ignite farmers' innovations

Interaction between science, technology and production is necessary for innovation in commercial and small-scale aquaculture. Production problems require specific technology developments that depend on basic and applied knowledge generation. Where there is an effective linkage between the institutions that generate new knowledge and the farmers using such knowledge, the technologies evolved will be further refined to best suit the farmers' specific needs. Even in the absence of such an effective linkage, innovative farmers of commercial magnitude have found their way to the technologies prevalent in different parts of the world and have evolved commercially viable systems. In most cases, they have followed an innovative approach to adapt validated fish farming strategies and technologies to their own environmental, socio-economic, cultural and political contexts.

Farmer innovation is encouraged by the need to maintain viable production. This is generally associated with economic returns. In some instances, social and environmental sustainability are also drivers for innovation. Social needs, such as food security, better income generation and the cultural history of fish in livelihoods have defined innovative pathways in aquaculture development; environmental needs, such as the preservation or restoration of local species, have also been drivers of innovation.

In the case of small-scale aquaculture, one of the main drivers for farmer innovation has been the increasing demand for aquaculture products. With the

declining catches from rivers and lakes, the price of fish has more than doubled in the last five years, thus providing impetus for aquaculture development. A profit-oriented approach has motivated farmers to increase farm productivity to meet and ensure consistency of supply. In continents other than Asia, this has resulted in not only adoption of Asian technology, but in many instances, the hiring of Asian technicians to guide aquaculture operations.

Critical to the promotion of farmer innovation in small-scale aquaculture, technical support and assistance from development agencies like FAO, the WorldFish Center, the World Food Programme (WFP), and other regional organizations like NACA and several NGOs have been forthcoming. However, success has come only with those interventions that have engaged and facilitated the farmers to improve on their own rather than by replacing government in direct intervention by providing free services and inputs (hand-outs). These interventions have been especially useful in supporting farmers to acquire the necessary technologies from elsewhere.

Main factors to consider

It should be noted that most of the factors listed below could be considered either as favouring or limiting factors for farmers' innovations; the positive or negative impacts depend on the context.

Environmental factors

Water availability and quality, land availability and soil quality, temperature, pluviometry and freshwater species biodiversity have helped innovative fish farmers to adapt the existing farming systems to a specific environmental context.

Socio-economic factors

There are many socio-economic factors that impact on farmers' innovative approaches, such as fish demand, marketability and market structure, public general infrastructures, existing traditional knowledge and technologies, access to inputs, information, extension services and materials. One of the most limiting factors for fish culture establishment and development in remote rural areas is the access to inputs (e.g. fish seed and feed) and markets. Lack of appropriate inputs has generated crucial innovative approaches all over the world. Another key factor pushing farmers to innovate is the demand for fish products in local markets. Limitations in the form of lack of traditional knowledge and aquaculture background in some rural areas are also factors affecting innovation, pushing farmers to adapt validated culture systems from other regions to suit their own local conditions. Lack of access to cash flow and information (through proper extension services and materials) are two other factors that generate innovations in order to improve production efficiency using available resources.

Political factors

Many political factors can be considered as both favouring and limiting factors for fish farmers' innovations, depending on the context. For instance, lack of an appropriate legal framework promoting development and expansion of aquaculture could push farmers to innovate using available resources to meet market demands, but just to a certain level; lack of adequate policies also limits the future expansion of the sector in a long-term perspective. In some isolated rural areas, there is a high demand for fish products; however, without specific support from the government (e.g. access to credits, technical knowledge), farmers are pushed to create, adapt and innovate using available resources. Finally, inadequate basic infrastructure and geographical isolation have also generated innovations and adaptations in many regions.

Factors that hamper farmers' innovations

Several factors hamper innovation. Lack of information on the biology and aquaculture techniques required is a contributing factor. At the commercial level, however, farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology. Although science and technology policies are evolving, funding for innovation is still limited.

The socio-economic context of a certain region is crucial for innovation, as it could limit what the farmers can use and adapt to aquaculture. For example, lack of simple mechanical tools and equipment makes many farmers' innovations untenable and impractical. Inability to use the new ICT technologies greatly inhibits farmers and removes them from the loop of global aquaculture information and technology. Among the major limitations for farmers to innovate is a lack of traditional knowledge on aquaculture and skilled and experienced extension services.

Another major limitation that has hindered faster progress of aquaculture is the lack of high-quality inputs such as feed and seed. With regard to feed availability, in most cases the private sector is reluctant to invest in the feed industry because of lack of a critical mass of farmers to generate effective demand, yet there cannot be a critical mass of farmers without quality feed.

The cost of capital is another big limitation: if it is available, normally it is with high interest. This greatly affects realization of potentially important ideas and innovations. However, a few governments in developing countries are making deliberate interventions to reduce the cost of capital by assisting the banks to manage some of the risks associated with agriculture investments.

As mentioned earlier, most of the factors that ignite farmers' innovations could also be considered as limiting factors as well. These include:

- inadequate extension services and lack of access to technical knowledge, information and other didactic materials;

- lack of capitalization of validated technologies;
- inappropriate technology transfer methodologies from technicians to farmers and from farmer to farmer;
- inefficient discussion platforms among stakeholders involved in aquaculture (e.g. technicians, experts, scientific community, politicians, extension workers, farmers, and local and international NGOs); and
- lack of communication and exchange of ideas and knowledge among fish farmers (i.e. through the establishment of fish farmers' networks or other farmer to farmer technology transfer mechanisms).

We should also consider as relevant limiting factors:

- inappropriate or not updated regulatory frameworks or specific policies for the promotion, development and expansion of small-scale aquaculture;
- lack of linkage between the public and private sectors;
- inappropriate extension materials and extension programmes;
- isolation;
- inadequate basic infrastructure and services;
- poverty and low socio-economic situation, in general; and
- difficult access to credit and aquaculture-needed inputs.

Organizational and policy changes needed to promote farmers innovations

Policy change should focus on the following areas:

- providing access to the required natural resources (e.g. water, land, feed and seed) and inputs for aquaculture production;
- supporting farmers' technology transfer and innovations;
- promoting farmer training;
- enhancing the role of farmers' organizations;
- providing economic incentives for commercial feed production and distribution;
- developing and providing aquaculture extension services;
- developing appropriate regulatory policies and strategic development plans to promote healthy development of aquaculture; and
- creating a policy environment that promotes good aquaculture practices and best management strategies.

In the emerging era, public and private-sector partnerships can stimulate healthy development. Such partnerships can be best directed to promote and capitalize the farmers' innovations and validate indigenous knowledge. To accomplish this, large-scale public and private investment in aquaculture research and development should take place.

Globally, several countries have initiated programmes to document indigenous knowledge, validate it scientifically and undertake further research wherever necessary and disseminate such information for the greater benefit of society

at large. In China, the Chinese Historical Fisheries Research Division has attempted to document the historical developments in aquaculture. In India, The National Innovation Foundation, created by the Government of India, reviews indigenous knowledge and practices regularly, documents them and scales up such knowledge based on the potential for production and commercialization by ensuring benefits to original inventors. The government has made a huge investment to promote innovations at all levels, including the farming community, to harness the potential innovative capacity of the billions of people and disseminate such innovations by ensuring that all the ethical principles are followed with regard to intellectual property rights. Annual exhibitions organized by the National Innovation Foundation of India attract large numbers of entries (generally several thousands) each year.

In the agriculture sector, the Indian Council of Agricultural Research (ICAR) undertook a major study throughout the country to document all the traditional knowledge prevalent in agriculture and validate it through scientific investigation. However, such indigenous knowledge-based information was scant and currently, the Central Institute of Fisheries Education has undertaken a project to document all such indigenous knowledge. The number of entries received in aquaculture is reported to be small, while in the case of fishing and fish processing, many examples have been received from different parts of the country.

On innovation, one of India's widely read newspapers, "The Hindu", has carried a story on farmers' innovation in its Thursday issue every week for the past ten years (.Prabhu, 2000). This event has helped to create greater awareness of the positive role played by farmers' innovation in bringing innovation to the attention of the general public. Most of the agricultural universities in India also have progressive farmers on their boards of management, at the highest level, with a view to drive universities' policies and programmes to be farmer friendly. The University of Agricultural Sciences, Dharwad in Karnataka, India conferred an honorary D.Sc. to a farmer who has made several innovations in agricultural crops cultivation (Prabhu, 2009). However, there are several innovative farmers who believe that their innovations are copied by scientists and published as their own work, sometimes without even an acknowledgment. Innovations are being largely driven by common sense and curiosity, and it is necessary that the scientific community recognize the innovative potential of all people involved in the agrolivestock sector as innovators, since they face the challenges in their daily activities and invent new ways through curious observation. Evolving new ways to promote farmers as partners in scientific investigations would bring greater benefits. Farming-systems research and farmer participatory research that recognize the value of carrying out field work through the active participation of farmers and that also promote farmers as owners of innovations are not well known. With the increasing opportunities for information sharing globally, with least cost and greater speed, and through electronic platforms, there is a huge opportunity for various organizations, including FAO, to document and capitalize

on indigenous knowledge and farmers' innovations and to disseminate successful technology transfer strategies widely.

The way forward

FAO should encourage educational and research institutions involved in aquaculture to document the indigenous knowledge prevalent in their area of operation, validate them scientifically wherever possible, and make such information available to the global community through an electronic platform, with due consideration to protecting the indigenous knowledge and promoting innovations of farmers under intellectual property rights (IPR).

The rapid expansion of the aquaculture sector in Asia, particularly by the small-scale farmers, clearly demonstrates the innovative ability of the farmers in adapting the technologies to their farming conditions. Wherever such integration with existing farming systems has been possible, aquaculture has expanded phenomenally. It is essential to support the integration of aquaculture with the prevailing farming systems. Development without focus on sustainability would hinder aquaculture improvement. Hence, a careful balance on integration, considering health of the system and the consumers, should be promoted.

Policy support and good governance promote innovations and disseminate knowledge through active partnerships, contributing to the rapid expansion of aquaculture. However, restrictive policies have also hampered aquaculture development and as a result, large parts of the resources available to aquaculture remain unutilized.

Dissemination of information through well-planned scientific interventions has always been successful and has shown maximum impact on society and on the development of the sector. Sustainability should be the key issue when considering mechanisms to disseminate information. As the circumstances vary from location to location and context to context, success and sustainability are not assured, even for proven technologies. Hence, people should be encouraged to undertake adaptive approaches to use of the information provided. Free access to information will help the people to make well-informed decisions.

Priority actions

The following actions are recommended:

- Document indigenous technology and innovations prevalent in different countries, validate the technologies through scientist-farmer partnerships and scale up good practices to bring better benefits to people.
- Promote interaction between the scientific community, students and farmers at the field level.
- Promote research, outreach and extension systems in partnership with policy-makers, scientists and farmers to address field problems.

- Invite policy-makers to experience field realities with farmer innovators.
- Increase the role of farmers in research planning and implementation.
- Promote farmer to farmer exchange in all possible contexts and opportunities.
- Place emphasis on capacity-building skills with knowledge of extension staff.
- Disseminate documented examples of indigenous knowledge and innovations through new technologies and institutions, particularly through regional networks and their Websites.
- Encourage relevant stakeholders (including policy-makers) involved in aquaculture to incorporate farmers' innovation, traditional knowledge and technology transfer at a small scale, and to incorporate these concepts into their project proposals, feasibility studies, food production strategies, implementation plans and projects affecting local communities.

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Part IV – Phuket Consensus





Aquaculture Development Beyond 2000

The Bangkok Declaration and Strategy

Conference on

Aquaculture Development in the Third Millennium

20-25 February 2000 Bangkok, Thailand

April 2000

Preface

The first major international Conference on Aquaculture organised by FAO was held in Kyoto, Japan in 1976. The Conference adopted the “Kyoto Declaration on Aquaculture.” In February 2000, some 540 participants from 66 countries and more than 200 governmental and non-governmental organisations participated in the “Conference on Aquaculture in the Third Millennium” in Bangkok, Thailand. This conference was organised by the Network of Aquaculture Centres in Asia-Pacific (NACA) and the FAO and hosted by the Government of Thailand. Additional support was provided by the European Union (EU), the Australian Agency for International Development (AusAID), the Canadian International Development Agency (CIDA), the Danish Centre for Environment and Development (DANCED), the Department of Agriculture, Forestry and Fisheries of Australia (AFFA), the Rockefeller Brothers Fund, and the World Bank-Netherlands Partnership Program.

Throughout 1999, NACA and the FAO facilitated the preparation of reviews on aquaculture developments in Africa, Asia, Europe, Latin America, North America, the countries of the former USSR, the Near East, and the Pacific Island nations and held expert meetings to consider major trends in aquaculture development. Fourteen Thematic Reviews on selected aspects of aquaculture were promoted and eight overviews on key issues were prepared for presentation and discussion at the Conference. All participants to the Conference received extended summaries of all material prepared. Twenty plenary presentations and discussions, and 12 workshop sessions facilitated by expert panels enabled participants to discuss and prioritise major issues and strategic actions for follow-up.

Major themes discussed included policy-making and planning for sustainable aquaculture development (covering food security and poverty alleviation, rural development, stakeholder involvement, incentives, and legal and institutional frameworks); technological and R&D priorities (including systems/species,

genetics, health management, nutrition/feeding, and culture-based fisheries); human resource development; international trade; product quality, safety and marketing; regional/inter-regional co-operation; financing; and institutional support.

Against this background, the Conference participants discussed priorities and strategies for the development of aquaculture for the next two decades, in the light of the future economic, social and environmental issues and advances in aquaculture technologies. Based on these deliberations, the participants adopted the **Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000**. The Conference encouraged States, the private sector and other concerned stakeholders to incorporate in their strategies for aquaculture development the key strategy elements identified during this Conference.

The proceedings of the Conference, including global and regional reviews on trends in aquaculture development, thematic reviews, keynote addresses and other invited presentations will be published by NACA and FAO.

NACA and FAO acknowledge all individuals and agencies who assisted in the conference process.

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Aquaculture Development Beyond 2000

The Bangkok Declaration and Strategy

1 Preamble

- 1.1 The first international Conference on Aquaculture organised by the Food and Agriculture Organization of the United Nations (FAO) was held in Kyoto, Japan in 1976. The Conference adopted the “Kyoto Declaration on Aquaculture.”
- 1.2 In February 2000, some 540 participants from 66 countries participated in the “Conference on Aquaculture in the Third Millennium” in Bangkok, Thailand. This Conference was organised by the Network of Aquaculture Centres in Asia-Pacific (NACA) and the FAO and hosted by the Government of Thailand.
- 1.3 Throughout 1999, NACA and the FAO facilitated the preparation of reviews on aquaculture developments in Africa, Asia, Europe, Latin America, North America, the countries of the former USSR, the Near East, and the Pacific Island nations and held expert meetings to consider trends in aquaculture development. Thematic Reviews on various aspects of aquaculture were also conducted. Participants to the Bangkok Conference were informed of the findings and conclusions of these activities.
- 1.4 Against this background, the Conference participants discussed strategies for the development of aquaculture for the next two decades, in the light of the future economic, social and environmental issues and advances in aquaculture technologies.
- 1.5 Based on these deliberations, the participants to the Conference adopted the following Declaration.

2 The declaration

We, the participants to the Conference on Aquaculture in the Third Millennium, Bangkok 2000, recognise that:

- 2.1 during the past three decades aquaculture has become the fastest growing food-producing sector and is an increasingly important contributor to national economic development, the global food supply and food security;
- 2.2 aquaculture consists of a broad spectrum of users, systems, practices and species, operating through a continuum ranging from backyard household ponds to large-scale industrial systems;
- 2.3 the per caput supply of food fish from capture fisheries is likely to decline with population increase;
- 2.4 a great proportion of aquaculture production comes from developing countries, where aquaculture will continue to contribute to peoples' livelihoods, food security, poverty alleviation, income generation, employment and trade;
- 2.5 there has been a significant increase in commercial and industrial aquaculture, both in developed and developing countries, that has contributed to food supply, export income and trade;
- 2.6 globally, aquaculture is at varying stages of development and will require different strategies for growth;
- 2.7 the potential of aquaculture to contribute to food production has not yet been realised across all continents;
- 2.8 aquaculture complements other food production systems, and integrated aquaculture can add value to the current use of on-farm resources;
- 2.9 aquaculture can be an entry point for improving livelihoods, planning natural resource use and contributing to environmental enhancement;
- 2.10 responsible aquaculture practitioners are legitimate users of resources;
- 2.11 education and research will continue to make a significant contribution to the growth of aquaculture;
- 2.12 some poorly planned and managed aquaculture operations have resulted in negative impacts on ecosystems and communities;
- 2.13 aquaculture has also been negatively impacted by other unplanned activities;
- 2.14 the continued growth of aquaculture will occur through investment by the private and public sectors;

- 2.15 effective national institutional arrangements and capacity, policy, planning and regulatory frameworks in aquaculture and other relevant sectors are essential to support aquaculture development;
- 2.16 improving co-operation amongst stakeholders at national, regional and inter-regional levels is pivotal for further development of aquaculture;
- 2.17 the potential of aquaculture to contribute to human development and social empowerment cannot be fully realised without consistent, responsible policies and goals that encourage sustainable development;

and declare that:

- 2.18 the aquaculture sector should continue to be developed towards its full potential, making a net contribution to global food availability, household food security, economic growth, trade and improved living standards;
- 2.19 the practice of aquaculture should be pursued as an integral component of development, contributing towards sustainable livelihoods for poor sectors of the community, promoting human development and enhancing social well-being;
- 2.20 aquaculture policies and regulations should promote practical and economically viable farming and management practices that are environmentally responsible and socially acceptable;
- 2.21 national aquaculture development processes should be transparent and should take place within the framework of relevant national policies, regional and international agreements, treaties and conventions;
- 2.22 in pursuing development, States, the private sector, and other legitimate stakeholders should cooperate to promote the responsible growth of aquaculture;
- 2.23 strengthened regional and inter-regional co-operation should increase the efficiency and effectiveness of aquaculture development efforts; and
- 2.24 all parties formulating improved policies and implementing practices for aquaculture development should consider and where appropriate, build on the FAO Code of Conduct for Responsible Fisheries.

The following contains the major strategy elements based on the Conference session recommendations. The detailed recommendations from the sessions are given in the Conference Report.

3 Strategy for aquaculture development beyond 2000

States are encouraged to incorporate in their strategies for aquaculture development the key elements identified during this Conference.

The key elements are:

3.1 Investing in people through education and training

Further investments in education and training are essential to build the knowledge, skills and attitude of all people involved in the sector. Human capacity development can be made more cost-effective and responsive to needs through:

- using participatory approaches to curriculum development;
- improving co-operation and networking between agencies and institutions;
- multidisciplinary and problem-based approaches to learning;
- use of modern training, education and communication tools, such as the Internet and distance learning, to promote regional and inter-regional co-operation and networking in the development of curricula, exchange of experiences and development of supporting knowledge bases and resource materials; and
- providing a balance of practical and theoretical approaches to train farmers and provide more skilful and innovative staff to industry.

3.2 Investing in research and development

There is a need to increase investment in aquaculture research, whilst making efficient use of research resources and building the capacity of research institutions to be more responsive to development requirements through such mechanisms as:

- collaborative multidisciplinary research;
- stakeholder participation in research identification and
- improving linkages between research, extension and producers;
- collaborative funding arrangements between institutions and public and private sector organisations;
- efficient communication networks;
- regional and inter-regional co-operation; and
- a continued effort to build the skills of researchers involved in aquaculture development.

3.3 Improving information flow and communication

Efficient management of the sector requires improved information flows at the national, regional and inter-regional levels which will avoid duplication of effort and save costs, while encouraging consistency in areas such as education and training, policy-making, planning and the application of rules and procedures.

Improved information flows will increase institutional capacities for dealing with emerging issues and can be achieved by:

- establishing arrangements for sharing data and information;
- strengthening national capacity to determine data requirements and data selection and management;
- providing effective mechanisms for access to relevant and reliable information to all stakeholders; and
- making effective use of new technologies to improve information flows and management policies and practices within aquaculture.

The collection and dissemination of accurate and verifiable information on aquaculture may help to improve its public image and should be given attention.

3.4 Improving food security and alleviating poverty

Enhancing food security and alleviating poverty are major and complementary global priorities. Aquaculture has a special role in achieving these objectives because, firstly, fish is a highly nutritious food that forms an essential, if not indispensable, part of the diet of a large proportion of the people in developing countries. Secondly, while aquaculture contributes to the livelihoods of poor farming households, particularly in areas of Asia where it is a traditional farming practice, there is a huge, unfulfilled potential in most countries, as aquaculture is a relatively recent and underdeveloped sector as compared to agriculture and animal husbandry. Aquaculture could improve food security, provide entry points and contribute to sustainable livelihoods for the poor through:

- promoting poor-people-centred development focus in aquaculture sector policies, wherever appropriate;
- promoting systems to farm low-value fish affordable to the poor, particularly small-scale household production in rural areas where it may be the only source of fish due to poor infrastructure;
- disseminating information about the nutritional advantages of fish to vulnerable groups of people such as pregnant and lactating women, and families with infants and pre-school children;
- greater use of holistic, participatory approaches to identify the poor and assess their needs; and to develop and extend aquaculture technologies appropriate to the resources and capabilities of poor households;
- recognising that the development of small-scale aquaculture requires initial public sector support, with more support needed and for longer periods for poorer target groups; and
- empowering poor stakeholders to actively participate in policy decision-making.

3.5 Improving environmental sustainability

There is a need to develop and adopt policies and practices that ensure environmental sustainability, including environmentally sound technologies and

resource efficient farming systems, and integration of aquafarms into coastal area and inland watershed management plans. Improvements in environmental sustainability can be achieved through:

- development, adoption and application of environmental, economic and social sustainability assessment criteria and indicators of aquaculture development;
- development of and support to implementation of improved management practices and codes of good practice for aquaculture sectors that are supported by enforceable regulations and policy;
- research and development of resource-efficient farming systems which make efficient use of water, land, seed and feed inputs; exploring the potential for commercial use of species feeding low in the food chain; and utilising enhancement techniques;
- development of strategies to integrate aquaculture into the coastal areas and inland watershed management plans and ensuring aquaculture developments are within local and regional carrying capacities;
- promotion of good practices for environmental management of aquaculture; and
- promotion of aquaculture, where appropriate, as a means of improving environmental quality and resource use.

3.6 Integrating aquaculture into rural development

With the goal of increasing the impact of aquaculture on rural development and poverty alleviation, strategies are required to put people as the focal point for planning and development for such programmes and to integrate aquaculture into overall rural development programmes. In essence, this can be achieved through:

- integrating aquaculture planning within overall rural development planning, taking into account multi-sectoral developments and views, and multi-sectoral co-ordination which brings agencies together;
- integrating aquaculture with other rural development efforts to improve resource utilisation, such as integrated coastal area management and inland watershed management;
- awareness-raising in other rural development sectors of the potential of aquaculture to improve livelihoods;
- using participatory approaches to involve stakeholders in policy-making, planning, implementation and monitoring; and
- the documentation and wide dissemination of information on experiences and utilisation of good practices and benefits thereof.

3.7 Investing in aquaculture development

Future investment in aquaculture should be made with long-term strategies in mind to ensure sustainability. Private sector investments make the biggest contribution to aquaculture development, but adequate public sector finance for capacity building, institutional development and infrastructure, is indispensable for society to reap the full benefits of a well managed and efficient aquaculture sector.

Sound investment strategies should include:

- providing initial financial encouragement and facilitating investments in aquaculture development;
- encouraging continued public investment in rural and small-scale aquaculture in developing countries, and in applied research and farmer access to knowledge and capital;
- encouraging private sector funding and investment in aquaculture development and infrastructure which will provide the benefits of aquaculture to rural communities;
- developing mechanisms (e.g., investment screens, credit linked to performance or adoption of best management practices, performance bonds) which encourage the growth of environmentally and socially responsible aquaculture, including economic, educational and other incentives for responsible aquaculture;
- support to sponsorship of industry-driven codes of practice to promote responsible aquaculture;
- fostering a greater understanding within financial institutions and bilateral and multilateral assistance agencies regarding aquaculture development and its financial needs; and
- establishing credit schemes that support sustainable aquaculture, e.g., micro-credit programmes, particularly for small-scale development.

International development assistance is becoming increasingly directed towards poverty alleviation and needs to adhere to basic principles of social equity, including gender equity, environmental sustainability, technical feasibility, economic viability and good governance. The level of risk is important when supporting initiatives to address poverty alleviation.

To make efficient use of international donor resources, a programme approach to multi-sectoral development should be applied under which donors can more effectively co-operate and collaborate with each other. Ultimately, this should occur within comprehensive planning and development frameworks.

There is thus a need for donors to adopt more cohesive approaches and procedures.

3.8 Strengthening institutional support

One of the key issues for the growth of aquaculture will be the ability of countries and organisations to strengthen their institutional capacity to establish and implement policy and regulatory frameworks that are both transparent and enforceable. Incentives, especially economic incentives, deserve to be given more attention in the planning and management of aquaculture development.

Institutional capacity should be made more effective and strengthened through:

- developing a clear aquaculture policy, and identification of a lead agency with adequate organisational stature to play a strong co-ordinating role;

- developing, through a participatory approach, comprehensive and enforceable laws, regulations and administrative procedures that encourage sustainable aquaculture and promote trade in aquaculture products;
- providing education and training, research and extension services to support the development of enforceable legislation, policy and regulatory frameworks, encompassing economic and other incentives to improve aquaculture management;
- targeting not only government ministries and public sector agencies dealing with administration, education, research and development, but also organisations and institutions representing the private sector, NGOs, consumers and other stakeholders;
- developing mechanisms and protocols for the timely collection and reporting of statistics;
- sharing information on policies and legislation, rules and procedures that encompass best practices in aquaculture;
- clarifying legal frameworks and policy objectives regarding access and user rights for farmers; and
- improving the capacity of institutions to develop and implement strategies targeting poor people.

3.9 Applying innovations in aquaculture

The technologies for sustainable aquaculture development should provide a varied and adaptable “tool box” from which people can select and design the system which most effectively meets their needs and best fits the opportunities and constraints of the local environment. The delivery of such techniques requires efficient communication networks, reliable data on the merits and drawbacks of the various approaches, and help with the decision making process through which people choose their production systems and species.

As we move into the next two decades, water and land for aquaculture will become critical issues. New opportunities for aquaculture development will also emerge through improvements in science and technology for aquaculture systems.

The potential areas for further consideration include:

- technologies for sustainable stock enhancement and ranching programmes, and open ocean aquaculture;
- increased use of aquatic plants and animals as nutrient stripping;
- increased emphasis on integrated systems to improve environmental performance; and
- emerging technologies (e.g., recirculating systems, offshore cage culture, integrated water use, artificial upwelling and ecosystem food web management).

3.10 Improving culture-based fisheries and enhancements

Fisheries enhancements in inland and coastal waters include culture-based fisheries and habitat modifications in common pool aquatic resources, which require minimal food and energy inputs. These practices therefore provide important opportunities for resource poor sections of the population to benefit from relevant aquaculture technologies and permit efficient use of under-utilised, new or degraded resources. Culture-based fisheries in particular have considerable potential for increasing fish supplies from both freshwater and marine fisheries and generating income in rural inland and coastal areas.

The full potential of enhancements and culture-based fisheries could be achieved by:

- creating conducive institutional arrangements to enable and sustain investment in common pool resources;
- providing appropriate research and development inputs;
- managing environmental and other external impacts; and
- promoting effective regional co-operation and information exchange.

3.11 Managing aquatic animal health

Disease is currently an important constraint to aquaculture growth which has impacted both socio-economic development and rural livelihoods in some countries. Addressing aquatic animal health issues has, therefore, become an urgent requirement for sustaining growth of aquaculture, especially through proactive programmes. Harmonising health protection approaches and measures and effective co-operation at national, regional and inter-regional levels are needed to maximise the effectiveness of limited resources.

This can be achieved through:

- developing, harmonising and enforcing appropriate and effective national, regional and inter-regional policies and regulatory frameworks on introduction and movement of live aquatic animals and products to reduce the risks of introduction, establishment and spread of aquatic animal pathogens and resulting impacts on aquatic biodiversity;
- capacity building at both the institutional and farmer levels through education and extension;
- developing and implementing effective national disease reporting systems, databases, and other mechanisms for collecting and analysing aquatic animal disease information;
- improving technology through research to develop, standardise and validate accurate and sensitive diagnostic methods, safe therapeutants, and effective disease control methodologies, and through studies into emerging diseases and pathogens;
- promoting a holistic systems approach to aquatic animal health management, emphasising preventative measures and maintaining a healthy culture environment; and

- developing alternate health management strategies such as the use of disease resistant, domesticated strains of aquatic animals to reduce impact of diseases.

Establishment of an effective international mechanism, such as an international task force which is outcome-oriented with focussed strategies and milestones that are independent of vested interests, would be beneficial in reducing the losses due to diseases in aquaculture.

3.12 Improving nutrition in aquaculture

Nutrition and feeding strategies play a central and essential role in the sustainable development of the aquaculture sector. Feed development will need to give increased emphasis on efficient use of resources and reduction of feed waste and nutrient discharge. Fishmeal reduction in diets will be important to reduce feed costs and avoid competition with other users.

These can be achieved through:

- increasing the understanding of dietary nutrient requirements of cultured species, including their application to practical culture conditions;
- developing species-specific broodstock diets that allow complete domestication and maximal reproductivity and larval quality;
- better understanding of larval nutritional requirements in order to develop suitable compound diets, which will further reduce the need for live food;
- improving the understanding of the aquaculture farming systems and the potential nutrient loads and losses to the environment, to maximise nutrient retention efficiency;
- improving the use of agricultural and fishery by-products and non-food grade feed materials, and basing feeding strategies, wherever possible, on the use of renewable feed ingredient sources;
- better understanding of nutrient bioavailability and interactions of commonly used feed ingredients;
- better understanding of the mechanisms of nutrient modulation of disease resistance as well as improved strategies to minimise toxicity of nutrients and other compounds of feed origin;
- promotion of “good aquaculture feed manufacturing practice” and “good on-farm feed management;” and
- ensuring that limitations in the selection and trade of raw materials for aquaculture feeds are based on sound, documented scientific facts.

3.13 Applying genetics to aquaculture

Genetics has an important role to play in increasing productivity and sustainability in aquaculture through higher survival, increased turnover rate, better use of resources, reduced production costs and environmental protection. This will require resources, but the benefits in both the short and long term should justify these efforts.

There are many elements and practices of genetics that may be considered for aquaculture. Recognising that aquaculture has not benefited as much as terrestrial animal husbandry from the adoption of best practices such as selective breeding and stock improvement programmes, high priority should be given to the application of genetics in aquaculture. The interventions include:

- developing and utilising improved domestication and broodstock management practices and efficient breeding plans to improve production in aquatic animals;
- designing and promoting strategies for equitable dissemination of genetic techniques and genetically improved organisms;
- encouraging public awareness and providing information to consumers on the application of genetics;
- greater application of genetic technologies to the conservation of aquatic biodiversity; and
- addressing the potential implications for aquaculture, including environmental and human health implications, in a precautionary, safe and practical way.

3.14 Applying biotechnology

Biotechnology as a science has the potential to impact on all food production sectors. In the future the aquaculture sector will confront the issue of biotechnology through:

- developing and applying biotechnological innovations for advances in nutrition, genetics, health, and environmental management;
- addressing the potential implications for aquaculture of biotechnology, including GMOs and other products, in a precautionary, safe and practical way; and
- encouraging public awareness and providing information to consumers on the potential applications of biotechnology.

3.15 Improving food quality and safety

As consumer awareness increases, aquaculture producers, suppliers and processors will need to improve the quality of products and enhance product safety and nutritional value. The incentives for this will be potentially higher prices, lower insurance rates and increased consumer demand.

This can be achieved through:

- improvements in diets, feeding regimes and harvesting strategies to enhance product quality and nutritional value of aquaculture products;
- promoting the application and adoption of international food safety standards, protocols and quality systems in line with international requirements such as the Codex Alimentarius;
- adopting international protocols for residue monitoring in aquaculture and fisheries products;
- appropriate and informative labelling of aquaculture feeds, including information on additives, growth promoters and other ingredients.

- collection, analysis and dissemination of relevant and scientifically sound information to allow producers and industry operators to make informed decisions and ensure consumer confidence in the food safety of aquaculture products;
- application of appropriate safety assessments based on risk analysis and the precautionary approach prior to market approval, including products from modern biotechnology; and
- increasing consumer confidence in aquaculture products by ensuring that industry takes responsibility for the production and distribution of safe products, utilising systems that allow traceability of product ingredients, including information on packaging, processing and production conditions.

3.16 Promoting market development and trade

A focus on market development and trade will increase demand, add value and increase returns for aquaculture products. This will require developing marketing and promotional strategies for aquaculture products and understanding consumer requirements and changing market demands.

These goals can be achieved through:

- reducing trade barriers for aquatic products;
- assisting producers, processors and manufacturers in identifying markets for aquaculture inputs, products and technology;
- providing data for, and investing in, information technology based market-information systems that are easily accessed by producers and processors;
- researching changing consumption patterns, market segmentation trends and the emergence of new markets and products; and
- ensuring transparency in the chain of custody (“chain traceability”) of aquatic products and encouraging the provision of relevant information to consumers through product labelling (e.g., nutritional values, environmental friendliness).

3.17 Supporting strong regional and inter-regional co-operation

Over the years, regional and inter-regional co-operation has brought considerable benefits to aquaculture development through dissemination of knowledge and expertise. In an era of globalisation, further strengthening of this co-operation at all levels will ensure increased benefits for sectoral development and sustainability.

This could be achieved through:

- supporting and strengthening existing regional organisations;
- improving inter-regional collaboration and networking between existing regional organisations to ensure synergy;
- encouraging the formation and development of regional organisations for aquaculture development in regions where they are lacking; and
- facilitating in-country support for the establishment and operation of these organisations.

The Conference noted there are issues relevant to aquaculture development that require a strong global focus to be addressed and that this need might best be achieved by establishing a global intergovernmental forum within an appropriate existing international organisation, having sustainable aquaculture development as its primary focus, and with a mandate for discussion, decision and agreement on technical and policy matters.

4. Implementation

- 4.1 The Conference encourages States, the private sector and other concerned organisations to implement Strategies for Development of Aquaculture Beyond 2000;
- 4.2 The aquaculture sector has become considerably more diverse since the Kyoto Conference and has developed a broad range of stakeholders. This diversity provides considerable opportunity for productive co-operation.
- 4.3 The Conference recognises that the primary responsibilities for development and implementation of these strategies rest with States and their private sectors. The Conference recommends that States develop strategies through encouraging private sector development incorporating the key elements identified above.
- 4.4 The Conference further affirms that co-operative mechanisms among countries provide an excellent opportunity to co-ordinate and support the development of aquaculture, through sharing of experiences, technical support, and allocation of responsibilities for the varied research, education and information exchange. The fostering of co-operation among developing countries deserves special attention and support.
- 4.5 Furthermore, the Conference recommends that effective use of existing regional and inter-regional mechanisms be made, and that decision-makers seek to promote synergy and co-operation between existing organisations. Where effective regional inter-governmental organisations to promote co-operation in aquaculture development do not exist, such as in Africa and Latin America, building of such mechanisms, and sharing experiences with the existing regional networks, is recommended.
- 4.6 The Conference notes that there are considerable opportunities for enhanced regional and inter-regional co-operation among different partners including governments, non-governmental organisations, farmers organisations, regional and international organisations, development agencies, donors and lending agencies with a common interest in development through aquaculture.
- 4.7 In this regard, the Conference strongly recommends the development of an effective programme of regional and inter-regional co-operation to assist in implementation of the Strategies for Aquaculture Development Beyond 2000.

The Declaration and Strategy was drafted by a Technical Drafting Committee (TDC), taking into account the recommendations of all conference sessions, and the views and suggestions expressed by the participants during and after the Conference. The composition of the TDC is: Glenn Hurry and Chen Foo Yan (Co-Chairs), Uwe Barg, Pedro Bueno, Jorge Calderon, Jason Clay, Sena De Silva, Maitree Duangsawadi, Dilip Kumar, Le Thanh Luu, Modadugu V. Gupta, Joaquin Orrantia, Michael Phillips, Rolando Platon, Vincent Sagua, Sevaly Sen, Patrick Sorgeloos, Rohana Subasinghe, Rolf Willmann, and Wu Chao Lin.

Phuket Consensus: a re-affirmation of commitment to the Bangkok Declaration*

Preamble

The Kyoto Strategy for Aquaculture Development adopted in 1976 facilitated the transformation of aquaculture from a traditional to a science-based economic activity. It promoted technical cooperation among developing countries to expand aquaculture development.

The UNEP Convention on Biological Diversity that came into effect in 1993 reflected the world community's commitment to manage biodiversity for the welfare of present and future generations

The FAO Code of Conduct for Responsible Fisheries promulgated in 1995 enshrined the principles of sustainability and responsibility in the practice of fisheries, aquaculture and trade in aquatic products.

The Bangkok Declaration and Strategy adopted in 2000 articulated 17 strategic elements for aquaculture development. These could be broadly summarised as: (i) a responsible farmer is justifiably rewarded; (ii) costs and benefits are shared equitably; (iii) society benefits from the practice and products of aquaculture; (iv) adequate, affordable and safe food is available and accessible to everyone; (v) the environment is conserved for the next generation, and (vi) the development of the sector is orderly.

At the threshold of this millennium, in September 2000 in New York, the global community adopted the United Nations Millennium Declaration which set the eight Millennium Development Goals.

The Paris Declaration adopted in March 2005, provides the guidelines for the correct targeting, effective coordination and efficient management and utilization of external assistance.

In the third World Food Summit on food security held in November 2009 in Rome, the leaders of nations pledged their renewed commitment to eradicate hunger at the earliest possible date. Towards the end of the first decade in December 2009, the world agreed, in Copenhagen, to meet with resolve and a common purpose the challenges of climate change.

* "Phuket Consensus: a re-affirmation of commitment to the Bangkok Declaration" was adopted by the participants of the Global Conference on Aquaculture 2010, held in Phuket, Thailand from 22-25 September 2010.

These global accords, with the Bangkok Declaration and Strategy as the core instrument for aquaculture development, shall continue to guide the development and management of aquaculture beyond 2010 through the first quarter of this century.

Re-affirmation of the Bangkok commitment

In line with the above and recognizing that:

1. The principles and strategies advocated by the Kyoto Strategy for Aquaculture Development, the FAO Code of Conduct for Responsible Fisheries, and the Bangkok Declaration and Strategy have served well the processes and goals of aquaculture development;
2. The two assessments of progress made in responsible aquaculture development and trade conducted in this first decade of the millennium – the first, completed in 2005 and published as the State of World Aquaculture, the second in 2010 and appeared as the Global Aquaculture Review – have shown that:
 - the progress has been made possible largely by efforts made in line with the Bangkok Declaration and Strategy;
 - the Strategy continues to be relevant to the aquaculture development needs and aspirations of States; and
 - there are elements of the Strategy that require further strengthening in order to enhance its effectiveness, achieve development goals and address persistent and emerging threats;

Recommendations

We the participants of the Global Conference on Aquaculture 2010 re-affirm our commitment to the Bangkok Declaration and Strategy for Aquaculture Development and recommend these actions:

1. **Increase the effectiveness of governance of the aquaculture sector**, recognizing the crucial need for sound policies, strategies and plans in sustained development incorporating the principles of an ecosystem approach to aquaculture; and recognizing further that stronger institutions, improved capacity and more effective mechanisms of governance, including rules and regulations, the market, economic incentives, voluntary codes of practices, and responsible self-management, have enabled a more orderly and responsible development of aquaculture.
2. **Encourage and facilitate greater investments in scientific, technical and social innovations**, recognizing that these assist in the resolution of productivity and sustainability issues that had earlier been deemed intractable, extremely costly or impossible to solve.

3. **Conduct accurate assessments of the progress and contributions of aquaculture, including aquatic plants, to national, regional and global economies, poverty alleviation and food security**, recognizing that this will enable the aquaculture sector to formulate better-informed development policies, strategies and plans that governments and development partners will favourably consider for support and funding.
4. **Intensify assistance to the small farmers**, recognizing that the small (resource- limited and/or subsistence) farmers comprise the vast majority of aquaculture producers in the world and recognizing further that they are the most vulnerable to impacts of natural and economic risks.
5. **Support gender sensitive policies and implement programmes** that facilitate economic, social and political empowerment of women through their active participation in aquaculture development, in line with the globally accepted principles of gender equality and women's empowerment.
6. **Increase and strengthen collaboration and partnerships**, acknowledging the many economic and technical benefits to nations, governments and people, of Technical Cooperation among Developing Countries (TCDC), inter-regional cooperation, and institutional collaboration and partnerships; and further acknowledging that the capacities for sustainable aquaculture development and trade among regions and countries have been cost-effectively improved by economic and technical cooperation facilitated by appropriate investments in development assistance from donors and technical assistance from international development organizations.
7. **Give special emphasis on Sub-Saharan Africa and the least aquaculturally developed countries and areas**, recognizing the need to urgently develop their vast aquatic resource potentials to accelerate their social and economic development, and recognizing further that this will narrow the disparities among regions and countries and contribute to increased global aquaculture growth. In this regard, we recognize that technical cooperation should be further intensified using international and regional mechanisms.

Implementation

The implementation strategy and mechanisms for the Bangkok Declaration and Strategy continue to be valid and relevant. We note and commend the immediate initiative taken after the adoption of the Strategy in February 2000 to establish the FAO Subcommittee on Aquaculture of the Committee on Fisheries, and the subsequent support provided by FAO Member countries and other organizations and institutions to the formation of regional aquaculture network organizations.

We note and appreciate the stronger collaboration that was fostered among several regional and international agencies and bodies; the formation of a global

consortium on shrimp aquaculture and the environment; establishment of several regional aquaculture networks; and an increasing number of partnerships and alliances among government agencies, non government organizations, industry associations and farmer organizations. These cooperative mechanisms are illustrative of the increasing importance of cooperation in improving growth and enhancing the institutional environment for the sustainable development of the sector. These should be further strengthened and made sustainable with appropriate technical assistance and investments.

We recognize that a holistic approach to aquaculture development will promote effective and efficient synergies and linkages among the various economic sectors and leads to sustainable use of resources that are becoming scarce or increasingly demanded by other competing sectors.

We recognize that the lessons from the natural disasters and economic crises of this and the past decades could be an indication of impending threats to aquaculture development, which make us believe that the implementation of Bangkok Strategy shall benefit from the following considerations:

1. The rehabilitation of livelihoods from the tsunami of 2004 and other natural calamities, and the mechanisms adopted to cope with the global economic crises during the past decade have underlined the critical role of biodiversity in sustaining the flow of ecosystems services that enable rapid recovery and sustained development of aquaculture, the importance of infusing social and biological resilience into aquaculture systems and strengthening farmers' capacity to positively adapt to changes beyond their control; and the usefulness of risk management as a tool to reduce, mitigate and cope with the threats to farmers' livelihoods.
2. Economically viable and responsible aquaculture systems are resilient systems; adoption of better management practices, including by small-scale farmers based on cluster approach, enhance productivity and social and environmental responsibility; their net impact is to strengthen the ability of the aquaculture sector to successfully face the uncertainties and risks wrought by economic crisis and climate change.
3. The implementation of the Strategy should be guided by a governance mechanism that recognizes the power and limitations of the market is sensitive to negative public perception, promoted through intensified results-based consultations, public-private partnerships and cooperation, and monitored by FAO through progress reporting on CCRF.

The Global Conference on Aquaculture 2010 brought together a wide-range of experts and important stakeholders and reviewed the present status and trends in aquaculture development, evaluated the progress made in the implementation of the 2000 Bangkok Declaration and Strategy, addressed emerging issues relevant to aquaculture development, assessed opportunities and challenges for future aquaculture development and built consensus on advancing aquaculture as a global, sustainable and competitive food production sector. This volume, a yet another joint effort of FAO and NACA, brings you the outcome of the Global Conference on Aquaculture 2010, the much needed clear and comprehensive technical information on how aquaculture could be mobilized to alleviate global poverty and improve food and nutrition security in the coming decades.



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