

AQUACULTURE ASIA

Ecological ways to reduce WSSV impact
Linking farms and landscapes

Resilient shrimp farms
WSSV virulence





Aquaculture Asia

is an autonomous publication that gives people in developing countries a voice. The views and opinions expressed herein are those of the contributors and do not represent the policies or position of NACA.

Editor

Simon Wilkinson
simon@enaca.org

NACA

An intergovernmental organisation that promotes rural development through sustainable aquaculture. NACA seeks to improve rural income, increase food production and foreign exchange earnings and to diversify farm production. The ultimate beneficiaries of NACA activities are farmers and rural communities.

Contact

The Editor, Aquaculture Asia
PO Box 1040
Kasetsart Post Office
Bangkok 10903, Thailand
Tel +66-2 561 1728
Fax +66-2 561 1727
Website <http://www.enaca.org>

Submit articles to:
magazine@enaca.org

Printed by
Scand-Media Co., Ltd.

AQUACULTURE ASIA

Volume XIX No. 4
October-December 2014

ISSN 0859-600X

Special issue on the RESCOPAR Project

In this issue we highlight some of the research that emerged from the RESCOPAR Project, *Rebuilding resilience of coastal populations and aquatic resources: habitats, biodiversity and sustainable use options*. The project was coordinated by Wageningen University, in partnership with Cantho University (Vietnam), Mula-warman University and Bogor Agricultural University (Indonesia), the Indonesian Institute of Sciences, WWF Indonesia and NACA.

The project aimed to improve understanding of the ecological and social processes underlying the resilience of mangrove ecosystems and dependent communities, and to identify socio-political and spatial factors in the use, management and conservation of coastal aquatic resources. Specific objectives were to:

- Understand the social resilience of shrimp and fish based livelihoods and ecological resilience of mangrove and near shore estuarine ecosystems in South East Asia with specific reference to Indonesia (Kalimantan) and Vietnam (Ca Mau).
- Provide means that enable decision makers to access information/ knowledge generated on ecosystem processes, forces underlying the trade-offs in resource use at the various spatial and temporal scales.
- Facilitate a participatory and transparent decision making process by elucidating the position of stakeholders with regard to management tools and interventions.

The research themes of the project included:

- Impacts of spatial arrangements and temporal changes of aquaculture and fisheries related activities in coastal aquatic ecosystems.
- Spatial interactions and resilience of shrimp pond mangrove forest ecosystems.
- Trade-offs and feedback in resource use patterns, institutions and livelihoods.
- Governance arrangements facilitating change in use of aquatic natural resources.

The project provided a number of PhD scholarships to students in the region, and it is the research findings of some of these students that you will find in this issue. Enjoy!

Simon Wilkinson

AQUACULTURE ASIA

Sustainable aquaculture

Peter Edwards writes on rural aquaculture: Promising aquaculture practices for sustainable intensification 3

Culture and breeding of *Archocentrus spilurum* at Tuticorin District of Tamil Nadu, India 16
Linga Prabu, D. and M. Kavitha

Searching for ecological ways to reduce WSSV impact 19
Roel Bosma, Eleonor Tendencia, Marc Verdegem and Johan Verreth

Fisheries and aquaculture-based livelihoods prospects in East Kalimantan, Indonesia 21
Bambang Indratno Gunawan, Rini Kusumawati, Leontine E. Visser and Roel H. Bosma

Linking farms and landscapes in the governance of sustainable Vietnamese shrimp aquaculture 24
Tran Thi Thu Ha, Simon R. Bush, and Han van Dijk

People in aquaculture

Resilience of shrimp farming based livelihoods in the Mekong Delta, Vietnam 27
Tran Thu Phung Ha, Han van Dijk, Leontine Visser, Roel Bosma

Aquatic animal health

Farming system affects the virulence of white spot syndrome virus (WSSV) in penaeid shrimp 31
Tran Thi Tuyet Hoa, Nguyen Thanh Phuong, Mark P. Zwart, Mart C.M. de Jong and Just M. Vlak



Above, below: Small traders, Vietnam.

CONTENTS



Integrated shrimp / mangrove farm.

Extensive shrimp pond, Kalimantan.

Peter Edwards writes on

Rural Aquaculture

Promising aquaculture practices for sustainable intensification

Introduction

The human population is predicted to continue to grow for the next 40 years before stabilising at a minimum of 9 billion people. The challenge of feeding this huge global population is three-fold: to meet the food demand of this fast-growing and more affluent population; to do so in both environmentally and socially sustainable ways; and to ensure that the world's poorest people do not go hungry (Godfray et al., 2010). Major issues of importance to the future of global agriculture are: limits on land and water resources; the need for a significant increase in production from technological change to propel sustainable intensification; not simply to maximise productivity; and to optimise food production across complex land (and water) scapes of production, rural development, environment, social justice, and food consumption outcomes (Pretty et al., 2010). Quoting from Godfray et al. (2010): "there is no simple solution to feeding 9 billion people....a broad range of options.... needs to be pursued simultaneously.... we are hopeful about scientific and technological innovation in the food system....(but)....the goal is no longer simply to maximise productivity, but to optimise across a far more complex landscape of production, environmental, and social outcomes".

The concept of sustainable intensification, defined narrowly as producing more outputs from the same area of land, emerged in agriculture which is faced with limited potential for increase in area of terrestrial crops and livestock. FAO has recently published a policy maker's guide to the sustainable intensification of smallholder crop production (FAO, 2011) that inspired the organisation of a regional consultation on the sustainable intensification of aquaculture in Bangkok in 2012. In

contrast to plant crops and livestock, aquaculture as the third but relatively underdeveloped food producing sector has great potential to expand in area as well as to intensify sustainably in both terrestrial and marine environments in land-and water-based systems; aquatic farms may be integrated with or replace crops and livestock as stand-alone systems on land as well as be established in natural and artificial inland and coastal water bodies.

Sustainable intensification of aquaculture needs to be considered broadly from social as well as environmental points of view because a primary driver of intensification for small-scale farming households that dominate Asian aquaculture as well as agriculture in Asia, at least in terms of number of farms if not in total production, is their desire to improve their livelihoods and increase income. The contribution that aquaculture could make to future food supplies through more widespread dissemination of existing as well as new practices needs to be explored, with due attention to better management practices (BMPs) and site selection, as well as the sustainable intensification of aquaculture production per unit area or volume of the culture system.

Promising aquaculture practices for sustainable intensification are presented which combine some of principles of traditional aquaculture to reduce the adverse environmental impact of modern pellet-fed aquaculture as well as to reduce the cost of production. This is followed by a selection of current aquaculture practices (rice/fish culture; case studies of the culture of carps, tilapias and striped catfish in ponds and/or cages; culture-based fisheries and aquatic macrophytes) as future increased fish production is most likely to be provided by more widespread dissemination of current practice



Dr Edwards is a consultant and Emeritus Professor at the Asian Institute of Technology in Thailand where he founded the aquaculture programme. He has over 30 years experience in aquaculture education, research and development in the Asian region. Email: pedwards1943@gmail.com.

although with increasing attention given to BMPs and better site selection. The final section discusses the aspirations and needs of small-scale farmers with a call to consider sustainable intensification not only in terms of increased production but also in social terms through the diversification of livelihoods through aquaculture.

Promising aquaculture practices

Most global aquaculture fish production is from ponds, followed by cages and pens, with production from rice fields, raceways, recirculation systems and tanks far behind. Ponds are the major grow-out system for freshwater fish production and are likely to remain so in the future (Boyd and Chainark, 2009). These authors outlined the evolution of technology to increase pond production: initially manures and chemical fertilisers to increase natural food, followed by pelleted feed to provide more nutrition for the fish and then mechanical aeration to increase the supply of dissolved oxygen and thereby allow greater input of feed.

Unfortunately, increased intensification of fish production is accompanied by the release of nutrients and organic matter in effluents or on pond draining which may cause pollution in the external

environment. Significant amounts of wastes in pond culture are treated by the pond ecosystem during the culture cycle although with intensification of production an increasing amount of waste is discharged directly to the external environment and in most cases the farmer does not bear the cost of its treatment (Boyd et al., 2007).

Cage technology has great potential for expansion in inland and coastal as well as off-shore waters although there may be constraints. Without adequate control of cage density there is a threat from auto-pollution within confined water bodies such as reservoirs leading to eutrophication of the water body and frequent mass fish kills. External pollution from agricultural, industrial and domestic effluents and wastes is also an increasing threat to cage culture, especially in open or flowing water bodies such as rivers. Cage-based production may be ultimately unsustainable due to increasing pollution in rivers which leads to disease and occasionally causes mass fish kills.

Research and development are being carried out on aquaculture systems that incorporate one or more of the principles of traditional aquaculture to reduce the adverse environmental impact of industrial aquaculture in which a single target organism is fed with formulated feed, and mostly in monoculture, and/or to lower the cost of production (Edwards, 2004, 2009; Milstein, 2005; Azim and Little, 2006). Traditional aquaculture has been developed by farmers or local communities using on-farm or locally available resources in contrast to industrial aquaculture which is science/industrial-based, in particular in the use of agro-industrially manufactured feed or inorganic fertilisers. Industrial aquaculture is analogous to the "Green Revolution" in agriculture in terms of nutritional inputs.

Traditional aquaculture is integrated with other human activity systems as these provided the only sources of nutritional inputs for farmed aquatic organisms before the relatively recent advent of agro-industrially manufactured feeds. Integration of aquaculture with livestock (a type of IAAS) and human sewage or wastewater (a type of integrated peri-urban aquaculture system or IPAS although nightsoil reuse in rural as well as urban and peri-urban areas is traditional practice in several countries) was developed primarily for aquaculture to benefit from the nutrients contained in wastes to fertilise fish ponds to produce fish rather than to treat the wastes although the latter of course was an important secondary benefit.

Promising aquaculture practices for sustainable intensification are presented: the use of chemical fertilisers, the 80:20 polyculture system, the combined use of chemical fertilisers and pelleted feed, aquaponics, biofloc systems, double cages to reduce wastes from cages in enclosed water bodies, cage-in-pond system, and integrated multi-trophic aquaculture. Low-volume high-density (LVHD) cage culture and open ocean aquaculture, although entirely modern in inspiration, are also included as promising aquaculture practices. Although not reviewed here as each topic warrants a separate review, there will be a need to explore promising emerging exotic as well as indigenous species; improved genetic selection and domestication of species and varieties; improved seed quality; new feed ingredients and more efficient feeds and feed utilisation; strengthened aquaculture bio-security and health management; and better risk management.

Chemical fertilisers

'Modern' inorganic fertilisers may be used to 'green' ponds i.e., to produce high-protein phytoplankton for feed for plankton feeding carps and tilapia. Inorganic fertilisers are a cheaper source of nitrogen and phosphorus than nutrients contained in formulated feed; and furthermore, by using formulated feed as a supplementary rather than as a complete feed in a chemically fertilised pond system, the amount of pelleted feed used as well as the food conversion ratio (FCR) can both be reduced considerably. Inorganic fertilisers may be used by both small-scale farmers with limited on-farm resources as well as by large-scale farmers to reduce feed costs, especially in nursing and early grow-out when fish are small, but also in a pellet-fed inorganically fertilised 'green water' pond system. Chemical fertilisers are widely used on resource-poor small-scale farms to augment the limited supply of livestock manure e.g., in Bangladesh and India as well as on large-scale semi-intensive farms in India. The use of chemical fertilisers to lower the cost of large-scale intensive culture of tilapia was proposed by Edwards et al., (2000).

80:20 system

Up to 8 species of carps are stocked in the traditional Chinese carp polyculture system in ponds but a 'modern' polyculture system has been introduced in China with a reduced number of species that combines production of a single high-value fish such as crucian carp (*Carassius carassius*), grass carp (*Ctenopharyngodon idella*), or tilapia (*Oreochromis* spp.) fed with pelleted feed with traditional Chinese polyculture with filter-feeding silver carp to remove phytoplankton and the carnivorous mandarin fish (*Siniperca chuatsi*) to control breeding in tilapia stocked ponds, wild fish and other competitors (Ye, 2002). In this 80:20 pond fish culture system about 80 % of the harvested weight is a high-value species and the other 20 % is a service species. Higher yields of a higher value fish are obtained than traditional polyculture technology. Feeding high-value target species with a high physical quality extruded and nutritionally complete feed leads to faster growth, higher production and better feed conversion with less adverse environmental impact. Yields in aerated pellet-fed ponds are 20-30 tonnes/ha, much higher than 5-15 tonnes/ha obtained in traditional carp polyculture.

Following 17 years of experience of trials and demonstrations in China, the American Soybean Association's International Marketing (ASA-IM) Program, in conjunction with the Chinese Extension Service, has recently promoted the 80:20 system in India, Indonesia, the Philippines and Vietnam (Manomaitis and Cremer, 2007).

There has been a similar decline in the number of stocked species in commercial aquaculture in other countries in Asia with dominance of one or two target species e.g. Indian major carps (rohu, *Labeo rohita* in monoculture or stocked with catla, *Catla catla* in India (Edwards, 2008), tilapia in Thailand (Belton and Little, 2008) and striped catfish (*Pangasianodon hypophthalmus*) in Bangladesh (Ali et al., 2013).

Combined use of chemical fertilisers and pelleted feed

Optimal pond fertilisation produces Nile tilapia (*Oreochromis niloticus*) of only about 200-250 g in 5 months and subsequent growth slows considerably as fertiliser-induced phytoplankton is insufficient to sustain a high growth rate. Nile tilapia fed a daily pelleted feed (commercial 30% crude protein floating pellet) at 50% satiation level in an optimally chemically fertilised pond produced growth as high as fish fed a 100% satiation ration because of substantial use of natural food by the fish (Diana et al., 1994). A second experiment showed that it was most economical to grow fingerlings from 15 to 50-100 g for about 3 months in a chemically fertilised pond before starting to also give pelleted feed at a 50% satiation rate (Diana et al., 1996). Fish of at least 500 g with higher value than smaller fish obtained in only fertilised ponds were harvested in another 3.5 months, with a FCR of only 1.0 due to considerable nutrition from natural food with an annual average extrapolated net yield of 21.0 tonnes/ha, almost double that of 8-11 tonnes/ha with chemical fertiliser alone. These experiments with pelleted feed as a supplementary feed in inorganically fertilised green water ponds used a feed application mean of 1.2 % and not the more usual feeding rate of 3-5 % body weight/day as significant nutrition was derived by filter feeding tilapia from plankton as well as from pelleted feed. The best strategy was reported to be to grow fish to 100-150 g with fertilisers alone before adding pelleted feed, with a considerable saving in feed cost.

Aquaponics

Aquaponics, the integration of aquaculture recirculating systems with hydroponics, the cultivation of vegetables without soil (Rakocy et al., 2006; Rakocy, 2007), has been generating increasing interest from scientists and potential commercial operators. A recirculating aquaculture system raises large quantities of fish at high density in a relatively small volume of water with the water treated to remove toxic fish metabolic waste and the water then reused in the system. The non-toxic nutrients and organic matter that accumulate are recycled to produce vegetables in an integrated system. The best known system has been run at the University of the Virgin Islands (UVI) on a pilot scale since the mid '70s. Pellet-fed tilapia are reared in tanks and the effluents are used to fertilise terrestrial vegetables such as basil, lettuce and okra on floating sheets of polystyrene in hydroponic tanks. Integrating vegetables as a secondary crop with fish improves the profitability of the combined system as the dissolved nutrients that accumulate from fish wastes approach the concentrations found in hydroponic nutrient solutions. However, iron must be supplemented for hydroponic vegetable production as its concentration derived from fish feed is insufficient. Another disadvantage is the large ratio of plant growing area relative to the fish rearing surface area, a ratio of 7.3 in the UV system. Aquaponic systems emphasise vegetable raising which may be an advantage if there is a good market for the vegetable crop.

Aquaponic systems based on the UVI design have been constructed and perform well at temperate sites in Australia, Canada, the Middle East and the USA and in the tropics in India, Mexico and Thailand (J.E. Rakocy, personal communication). The immediate potential is for niche markets in which consumers are willing to pay a higher price for high-quality fish and vegetables because aquaponic systems are expen-

sive to construct as well as to operate as they are energy intensive and require skilled staff. Aquaponics is mainly practiced at hobby and backyard levels although large-scale commercial systems have been constructed in the Middle East (J.E. Rakocy, personal communication). However, it may be more cost effective with need for less management skill to produce hydroponic vegetables in lower cost plant crop systems fertilised with inorganic fertilisers rather than through integration with a fish recirculating system (E. Pantanella, personal communication).

Biofloc

The principle behind bio-floc technology is addition of low-value carbohydrate-rich supplementary feed to constantly aerated intensive pellet-fed culture of fish or shrimp to stimulate nitrogenous waste uptake by heterotrophic bacteria which form suspended microbial flocs of bacteria, fungi, microalgae and organic detritus in the culture system water (Avnimelech et al., 1994). Bio-flocs convert most wastes into natural food organisms which can be consumed by filter-feeding freshwater fish such as tilapia and shrimp, in contrast to conventional biofilter systems which treat water in recirculation systems by removing particulate waste. Bio-flocs reduce excess nitrogen in the system and both waste disposal costs and feed costs.

There is tremendous interest in biofloc technology as indicated by numerous articles and the publication of a second edition of a book on biofloc technology by Yoram Avnimelech with numerous examples of commercial-scale production of shrimp and tilapia (Hargreaves, 2012). In Asia high yields of shrimp have been produced in Malaysia in a large-scale commercial system (Taw et al., 2013). However, biofloc technology is not without its detractors. In a pilot commercial-scale trial indoors in Thailand, there was inhibition of feeding and growth of tilapia associated with biofloc accumulation (Murray and Little, 2011). Even more noteworthy is that Charoen Pokphand Company, the major shrimp producer in Thailand with a major research and development (R and D) program does not use biofloc technology. The name given by the company to its shrimp culture technology, a highly intensive closed water cycle with sufficient aeration to remove waste ammonia through nitrification and to maintain a clean, oxidised bottom condition, is 'green technology' (McIntosh, 2008). Furthermore, CP Company's shrimp R and D manager is Robins McIntosh who was a pioneer in the development of biofloc technology in shrimp at Belize Aquaculture Ltd., in the 1980s. According to Hargreaves (2013), biofloc technology may be an advantage where water is scarce or land expensive. Constraints are the need for a high as well as reliable power supply to mix and aerate the water column to maintain an active biofloc in suspension; as well as a degree of technical sophistication in farm management. Furthermore the nutritional contribution of the biofloc at the highest levels of production is limited because of the overwhelming contribution of pelleted feed to the growth of the cultured animals; and there is an elevated respiration rate due to the high concentration of suspended solids which can accumulate to excessive levels (Hargreaves, 2013).

Double cages in enclosed water bodies

Aberyet et al., (2005) reported regularly occurring mass fish kills in three reservoirs in West Java, Indonesia, with loss of both caged fish and the naturally recruited fish in the open waters.

The cause is upwelling of deoxygenated deep waters, which also contain other noxious gases such as hydrogen sulphide due to anaerobic degradation of wastes accumulated from several years of intensive cage culture. Cage culture provides a major supply of fish for the domestic market in Java, mainly common carp (*Cyprinus carpio*) but also Nile tilapia, but its long term sustainability is questionable.

Cage farmers in Cirata have developed a double or two cage integrated system in which an outer cage surrounding the main pellet-fed cage is stocked with tilapia which feed on the fish wastes from the inner cage, mostly stocked with common carp, as they are dispersed by water currents. This system of integrated freshwater cage aquaculture provides an extra crop of fish without addition of more feed, a good example of fish crop diversification with increased farmer income, although it does not appear to be very effective in removal of caged fish wastes according to research carried out in Longtan Reservoir, Guizhou province, China (Liping et al., 2012). A 1 m wide outer cage stocked with bighead carp (*Hypophthalmichthys nobilis*), and Nile tilapia surrounded a 10 m square inner cage stocked with pellet-fed channel catfish (*Ictalurus punctatus*) in China. Although the bighead carp common carp and Nile tilapia in the outer cages that fed on phytoplankton, particulate waste from inner cage and periphyton increased body mass by 21% and 75%, respectively, the outer cage fish retained <1% of the total phosphorus to the cage, indicating that wastes from the pellet-fed cage culture were rapidly diluted and dispersed in the reservoir.

Low-volume, high-density cage culture technology

Low-volume high-density (LVHD) cage culture was developed by H.R. Schmittou of Auburn University in the 1970s and is now being promoted by the ASA-IM Program (L. Manomaitis, personal communication). The 1-27 m³ cages are square, made of nylon mesh and are suspended from a floating platform. Two basic technology packages are being promoted: 1-4m³ for freshwater environments, 1m x 1m x 1m (length x width x depth) with an effective water volume (amount of the cage actually under water) to 2m x 2m x 1m; and 8-27m³ for brackish and salt water environments, or 2m x 2m x 2m to 3m x 3m x 3m. With good water quality maintained in the water body through proper planning of cage density, the target biomass for fish in freshwater cages ranges from 100-250 m³ and for fish in brackishwater/marine cages it ranges from 50-75kg/m³.

Of course one of the primary goals of the ASAIM LVHD technology package is the promotion and use of high quality, formulated feeds but these do lead to improved fish growth and profitability compared to traditional feeds such as grass, waste vegetables, rice bran, trash fish as well as farm-made feeds with usually poor water stability. Traditional feeds usually also lead to decreased water quality as a great quantity of these items are needed since they are not as nutrient-rich as formulated pelleted-feed.

Cage-in-pond culture system

Experiments have been carried out to demonstrate the feasibility of a novel integrated culture system combining cage and integrated fish culture concepts with fish reared intensively on pelleted feed stocked in cages installed in a pond stocked with tilapia reared solely on caged fish wastes.

Thus, intensive pellet-fed cage grow-out is integrated with semi-intensive pond nursing of fingerlings in the same pond on spilled feed and 'green water' from fish faeces from the caged fish. The initial experiments were carried out with hybrid walking catfish (*Clarias macrocephalus* x *C. gariepinus*) (Lin, 1990) stocked in the cage but subsequent research developed a tilapia:tilapia integrated system with coordinated and integrated nursing and grow-out cycles (Yi et al., 1996; Yi, 1999).

Tilapia of about 100g were stocked in the cages and fed with commercial pelleted feed until they reached a marketable size of at least 500 g; and tilapia fingerlings were nursed until they were about 100 g in semi-intensive culture in the same pond, feeding solely on natural food produced by fertilisation of the pond with caged fish wastes. Thus, wastes from intensive cage culture of tilapia were treated and recycled in the static water semi-intensive pond in which the cages were suspended, with simultaneous nursing of fingerlings to stock the next cage culture cycle. Large-size tilapia of relatively high-market value could be raised in 3 months in the integrated system. A most important feature of the cage-pond integrated unit system is cage culture is protected from external agricultural, industrial and urban water pollution which increasingly threatens cage culture in rapidly developing and industrialising countries.

Integrated multi-trophic aquaculture

Integrated multi-trophic aquaculture (IMTA) is a relatively new concept and practice of marine aquaculture with open water and land-based systems. There has been a great deal of recent attention, especially from researchers on IMTA in which species from different aquaculture trophic or nutritional levels are incorporated horizontally into an integrated system with a primary objective to improve the environmental sustainability of fed aquaculture (Chopin et al., 2010, 2012; Troell, 2008). IMTA systems combine fed aquaculture of fish or shellfish such as abalone with extractive inorganic aquaculture of seaweed, organic aquaculture of shellfish and/or benthic detritivores such as sea cucumber.

Although mostly at the experimental stage in the West, commercial-scale open water integrated seaweed and mussel culture has been undertaken by salmon farmers in the Bay of Fundy, Canada (Barrington et al., 2009). Open water IMTA has been developed by farmers incidentally in China as first seaweeds, then scallops and later finfish cage culture were sequentially developed on a commercial scale in coastal bays (Fang et al., 2013a, b). Although research is underway to characterise the benefits of IMTA in China which is dominated in terms of production by seaweeds and shellfish with relatively limited production of caged finfish, the farmers who introduced various aquaculture commodities at different trophic levels did so as the technologies became available to take advantage of available space in the bay rather than to purposely benefit from nutrient recycling. This has been referred to as incidental IMTA i.e., 'not purposely designed cultivation of species of different trophic levels situated in close geographical proximity' (Reid et al., 2013). Small-scale farmers growing single crops to benefit from available space and waste nutrients may be more likely to benefit from IMTA than large scale corporate farmers with reluctance to devote management and the allocation of workers to farm and process an additional crop (Bunting and Shpigel, 2009).

There are ongoing research projects on IMTA in many countries with IMTA systems at or near commercial-level scale in Canada, Chile, China, Israel and South Africa (Chopin et al., 2010, 2012). According to these authors, sufficient data have now been accumulated to 'support proof of concept at the biological level so the next step is the scaling up of more experimental systems to commercial scale'. However, a different opinion is that while experimentation and financial modelling have demonstrated the feasibility of open water integration of finfish with seaweed and shellfish culture and have appeared to demonstrate attractive returns for investors, 'empirical evidence to substantiate claims concerning production rates, management demands, financial returns and economic performance is limited' (Bunting, 2013). Recent research has indicated that it is 'impractical to remove the full soluble inorganic nutrient load from a typical temperate commercial salmon farm through kelp culture' because it would not be possible to practically install sufficient rafts for the kelp (Reid et al., 2013). On a more realistic note, Chopin et al. (2012) pointed out that there should be an evaluation of the full value of IMTA component species, with the economic values of the environmental and societal services provided by the extractive species both recognised and accounted for.

Experimental land-based tank culture systems have been developed in Israel combining fish or abalone with seaweed; abalone, fish and seaweed; fish and shellfish; fish, microalgae and shellfish; and fish, shellfish, abalone and seaweed (Bunting, 2013). SeaOr Marine Enterprises in Israel farmed gilthead seabream (*Sparus aurata*), the seaweeds sea lettuce (*Ulva* sp.) and *Gracilaria* sp. and Japanese abalone (*Haliotis discus*) commercially until the mid-2000s when it was bought by a Japanese company. The company now uses the farm to produce *Ulva lactuca* using inorganic fertilisers for human food as it is more profitable than abalone and sea bream although the SeaOr farm was reported to have collapsed due to poor business management rather than a technology with little potential for profit (A. Neori, personal communication).

Major questions remain to be addressed on IMTA as outlined in a seminal paper entitled 'Integrated mariculture: asking the right questions' published a decade ago (Troell et al., 2003). A major constraint for open water IMTA is the probable inefficient and far from effective removal of fed species wastes by extractive organisms, especially in areas with strong currents which rapidly disperse cage waste. While there are reports of increased growth of shellfish and seaweeds in the vicinity of fish cages, the effectiveness of bivalve molluscs to reduce the environmental impact of marine fish farming has also been questioned (Navarrete-Mier et al., 2010). Another constraint is the value of shellfish and seaweeds may be much less than that of finfish leading to limited interest by fish farmers taking up IMTA. Perhaps the major constraint is that the economics of IMTA has only been considered in terms of financial benefits to farms and companies and not to socio-economic benefits to society (Chopin et al., 2010; Troel, 2009). It would appear that for IMTA to be sustainable, there is a need to assess overall environmental benefits so that incentives could be created for joint financing between national states and aquaculture industry (M. Troell, personal communication).

A final comment on terminology and system classification. IMTA may be considered as a type of integrated aquaculture-aquaculture system rather than as a generic, all inclusive or universal term for horizontal integration of aquaculture. IMTA

systems are better categorised or classified as integrated aquaculture-aquaculture systems or IAqAqS, a type or sub-system of integrated aquaculture systems as there are several types of such systems (Hambrey et al., 2008; Edwards, 2009).

Open ocean aquaculture

The open ocean offers tremendous potential to increase global aquaculture production with almost unlimited space and diffusion of wastes. The feasibility of aquaculture in the high-energy offshore environment with large and variable winds, swells and waves has been demonstrated with major advances in technology (Langan, 2009; Fredheim and Langan, 2009). A small-scale submersible fish cage has also been developed that would allow developing country fish farmers to move away from protected bays and into more exposed sites where there would be less conflict with other users of inshore waters (Chambers et al., 2011). However, technological, operational, economic and political challenges remain (Langan, 2009).

As off-shore cages need to be large and robust to function in the high-energy environment of the open ocean, they will need large capital investment and scale of operation for them to be feasible. However, Marine Harvest, the world's largest producer of salmon has announced their intention to develop open ocean sites (Bostock et al., 2010). FAO has launched an Offshore Mariculture Initiative, part of which is to estimate the spatial potential of offshore mariculture development for all maritime nations (Kapetsky et al., 2012). Furthermore, participants at the International Workshop on Open Ocean Aquaculture held in Germany in 2012, drafted the 'Bremerhaven Declaration on the Future of Global Open Ocean Aquaculture' with recommendations to promote and support R&D in open ocean aquaculture (Bremerhaven, 2013).

Current practices

Current aquaculture practices are discussed with an indication of their future potential as future increased fish production is most likely to be provided by more widespread dissemination of current practice although with increasing attention given to BMPs and better site selection: rice/fish culture, case studies of the culture of major species groups (carps, tilapias and striped catfish) in ponds and/or cages in various countries to illustrate potentials and constraints (based mainly on Edwards, 2009a with citation of more references), culture-based fisheries and aquatic macrophytes.

Rice/fish culture

The importance and potential of rice/fish culture has been grossly overestimated. Only about 1% of the world's rice fields are stocked with fish (Halwart and Gupta, 2004). A major trend has been conversion to ponds. It is a myth that rice/fish farming has ever been common or widespread in Asia although it has been practiced traditionally in a few areas of some countries e.g. Java in Indonesia and mountainous areas in South East China and Northern Lao PDR and Northern Vietnam (Edwards, 2009). While rice/fish farming is technically feasible there are numerous constraints and it is not often attractive to farmers with a relatively low return on producing small fish in mostly shallow modified rice fields although such fish may provide an important source of animal

protein, healthy fats, minerals and vitamins (Halwart, 2006). Rice/fish farming has been promoted widely as an integrated pest management practice as farmers who stock fish or crustaceans in the rice field reduce or eliminate the use of pesticides but the degree of sustainable adoption appears to be limited (Nandeesh, 2004).

There are exceptions to the above overall gloomy picture as rice/fish farming has developed fairly recently in some areas of some Asian countries in low-lying rice fields with seasonally available water or in remote areas with limited alternative livelihood options and with a high incidence of poverty, especially where there has been project support. Farming of the freshwater prawn (*Macrobrachium rosenbergii*) in trenched rice fields is widespread in Southwest Bangladesh where it plays an important role in the economy of the country, earning foreign exchange, and providing opportunities for employment. Freshwater prawn farming offers diverse livelihood opportunities for a large number of rural poor (Ahmed and Garnett, 2010; Ahmed et al., 2010). While prawn production in modified rice fields has been accompanied by considerable social and economic benefits, there are adverse environmental consequences such as overharvesting of wild snails for feed and relying on wild caught juveniles (Ahmed et al., 2008a). Although there are over 80 prawn hatcheries in the country, they mostly are inefficient and freshwater prawn farming depends mainly on the supply of wild larvae due to limited hatchery production, with indiscriminate fishing for wild larvae negatively impacting coastal fisheries (Ahmed and Troell, 2010).

Giant freshwater prawn is also becoming an increasingly important cultured species in the Mekong Delta of Vietnam, especially in rotation with rice (Nguyen et al., 2006; Nguyen et al., 2012; Tran N.H., personal communication; Nguyen V. H., personal communication). Although the prawn has been traditionally stocked in ponds and rice fields using wild seed, production has expanded rapidly since the 1990s after hatchery raised seed became available. Traditional culture systems are diverse with prawns grown in ponds and pens as well as in concurrent and rotational rice/prawn integration but the major system is rice cultivation in the dry season followed by rotation with prawn culture in the monsoon season with nylon net pens erected around the rice fields to facilitate water exchange.

Rice field aquaculture is reported to occur on a massive scale in China with over 1.5 million ha in 2001, including high-value river prawns (*Macrobrachium nipponensis* and *M. rosenbergii*) and Chinese mitten-handed crab (*Eriocheir sinensis*) grown concurrently with rice in trenches connected to the rice field (Fang, 2003).

Research has also indicated the feasibility of nursing common carp and Nile tilapia fry in irrigated rice fields in Northwest Bangladesh and the practice has spread without further project support (Haque et al., 2010).

Most inland fish ponds have been converted from rice fields, a trend that is likely to continue, especially in countries in which aquaculture is relatively new rather than those with well-developed aquaculture sectors where there is concern to maintain a minimum area of rice land for national food security. Thousands of hectares subject to flooding and able to produce only one rice crop annually have recently been converted to fish ponds in the Red River Delta, Vietnam

(Le, T. L., personal communication. "Concentrated" areas of 20-100 ha with 50-150 households have been converted to fish ponds with elevated dikes planted with trees and vegetables. The minimum return is 3-5 times higher than rice with a reduced risk of flooding.

Major species groups

Carps

Case studies are given of the recent development and dissemination of semi-intensive integrated aquaculture of carps in India and Bangladesh.

Carp polyculture in India

Traditional carp polyculture in India has a long history but used to be extensive with wild seed of native carps (mainly catla; rohu; and mrigal, *Cirrhinus cirrhosus*) stocked in ponds without intentional fertilisation or feeding. Fish hatcheries were established following the development of artificial breeding for native and introduced carps (common carp; grass carp; and silver carp, *Hypophthalmichthys molitrix*) that led to a more reliable source of seed. Indian scientists also developed so called 'composite culture', a semi-intensive polyculture of the six species of native and exotic species. A technological package developed through research was widely disseminated within the country and led to a significant increase in fish production. The package comprised eradication of predatory and weed fish, liming, stocking large fingerlings, fertilisation with cow dung and inorganic fertilisers, supplementary feeding with a 1:1 mixture of groundnut or mustard oil cake and rice bran or wheat bran, and provision of aquatic or terrestrial vegetation for grass carp.

Farmers in the Kolleru Lake region of Andhra Pradesh, often called the 'fish bowl' of India, have developed a much simplified semi-intensive carp technology with just two species, rohu as the dominant species and catla at a ratio of 80-90:10-20%, respectively (Nandeesh, 2001; Ramakrishna, 2007). As rohu has the highest market demand, farmers increased its stocking level from less than 20% recommended by researchers in 'composite culture' to more than 80% of stocked fish. Fish are fed a mixture of de-oiled rice bran and oil cake meal in perforated sacs suspended in the pond, a technique developed by farmers. Extrapolated annual yields range from 7.5-12.5 tonnes/ha with total annual carp production of 0.45 million tonnes from about 60,000 ha of ponds in Andhra Pradesh.

However, it has been suggested that the efficiency and profitability of carp culture in India could be increased through the replacement of indirect IAAS by commercial pelleted feed. The FCRs would be reduced from 3:1 to nearly 1:1 (feasible with pelleted feed in 'green water' ponds with secondary fertilisation from fish wastes), less labour for feed preparation and feeding, and better water quality compared to use of chicken manure and brans and oil cakes (Suresh, 2007).

Carp polyculture in Bangladesh

Traditional polyculture of Indian major carps in Bangladesh was also extensive as in India but semi-intensive fish culture has been introduced through projects with farmers now attaining extrapolated annual fish yields of 3-5 tonnes/ha in well-managed ponds using on-farm and locally purchased

manures, brans and oil cakes (ADB, 2005). Two important introductions of exotic fish to the traditional polyculture of indigenous carps are grass carp fed with on-farm vegetation such as grass, banana leaves and duckweed, and especially the filter-feeding silver carp which grows rapidly in green water ponds and comprises a major part of the harvest. Bangladesh IAAS are relatively simple compared those of China and countries in Southeast Asia as monogastric livestock (pigs and poultry) are not commonly raised on or near the pond; nor are vegetables commonly raised on pond dikes although cultivation of dike crops has developed recently in some areas (Ahmed et al., 2007; Edwards, 2007).

Small-scale household or homestead ponds are widespread in Bangladesh from the excavation of earth to raise the height of the house and surrounding area to minimise adverse effects of flooding in the largely deltaic landscape. It has recently been estimated that about 400,000 tonnes of carps are produced from such ponds with a similar production from 'commercial semi-intensive carp culture' (Belton et al., 2011).

Tilapias

Tilapias have recently become one of the most important groups of farmed fish with current global production about 3.5 million tonnes with considerable potential for further increase in production.

China

China is largest producer of tilapias at about 1.2 million tonnes and is also the largest exporter of tilapias in the world. Most of the tilapia produced in China for export is raised in pellet-fed aerated ponds and not in traditional IAAS (SEAT, Undated; Edwards, 2013). Culture is a tilapia dominated polyculture with silver and bighead carps stocked also to better utilise 'green water' and as extra species for the domestic market.

China exported 80% of the national tilapia production in 2010 but by 2012 this had fallen to about 50% because of declining demand in the main importing countries of Europe and the USA due to the global economic crisis. As a consequence of a declining farm gate price for tilapia, farmers were stocking fewer tilapia fingerlings and were also stocking other major target species in polyculture with tilapia such as grass carp or red bellied pacu (*Piaractus brachypomus*) to try to maintain profitability.

Thailand

Nile tilapia is traditionally mostly produced in ponds in Thailand in various types of IAAS, either in direct integration with livestock or indirectly using off-farm feedlot chicken manure and rice bran. Many of the larger commercial farms with indirect IAAS produce fairly large 0.4-0.6 kg tilapia that are often sold live or very fresh like those raised in cages (Belton and Little, 2008). Charoen Pokphand (CP) Company created a new premium fish, pla tap tim or ruby fish, a large 0.5-1.0 kg red tilapia for more affluent consumers that commands higher retail prices (Belton et al., 2006). CP also initiated contract farming of red tilapia in cages with the company supplying fry and feed to franchised aquatic feed dealerships which nurse fry to a size of 25-50 g for stocking in cages, and sells feed to and harvests and markets fish from contract cage farmers when they reach marketable size.

Contract farming is usually convenient for small-scale farmers as it arranges harvest and marketing of fish but contracted farmers experience problems with inconsistent availability of fingerlings, disagreements over purchase size and delayed harvesting at times of oversupply which disrupt production cycles.

Mass fish kills in rivers in Thailand are reported frequently in the press e.g., a loss of 8,000 tonnes of red tilapia in cages in the Chao Phya River due to pollution, probably from illegal and clandestine discharge of effluents from a factory.

Myanmar

Three large tilapia hatcheries were established in Myanmar to produce tilapia for export but they have ceased operation because they were unable to compete with China in terms of price. There has been limited domestic consumption of tilapia in Myanmar to date but this is now increasing with relatively large tilapia being seined from freely breeding tilapia present in typically large 12 ha rohu ponds. A total of 20 tonnes of tilapia were reported to be sold daily, mainly grilled on night markets in cities.

Philippines

The Philippines is a major producer of tilapia in fresh water and brackish water ponds as well as in cages in lakes and reservoirs. Tilapia cage culture in Lake Taal is intensive with almost total reliance on commercial feeds. The cage farmers are local people as they have legal access to farm the waters of the lake but they are caretakers rather than owner-operators because they cannot afford the high feed cost and thus enter into profit-sharing arrangements with external financiers who provide financial capital to carry out aquaculture. However, cage culture in Lake Taal suffers from occasional mass mortality as the estimated production of tilapia in cages, more than 100,000 tonnes, is 2-3 times the carrying capacity of the lake.

India

Tilapia has been a major farmed species in the wastewater-fed fish ponds in Kolkata for decades and provides an important source of fish for the city's poorer inhabitants. More widespread development of tilapia farming in India as a major commercial species has until recently been inhibited by concerns about possible adverse environmental impact on local fish biodiversity although this is unlikely to happen as tilapia is kept in check by native carnivorous catfish and snakehead, as experienced in other countries in South and Southeast Asia.

Striped catfish

There has been a recent rapid increase in production of striped catfish, initially and especially in Vietnam but also in Bangladesh, India, Indonesia, and Myanmar with Nepal now starting production. The fish has been traditionally raised in waste-fed ponds in Thailand and Vietnam but with poor flesh quality due to a high fat content and off-flavour.

Vietnam

Striped catfish farming has developed in over a decade from a household small-scale waste-fed pond system to one that produced more than 1 million tonnes of fish and generated an export income of over US\$ 1 billion in 2010 (De Silva and Phuong, 2011). It has the highest average production ever recorded for the primary production sector, ranging from 200 to 400 tonnes/ha/crop.

The explosive development of striped catfish farming started just over a decade ago following the development of hatchery-based mass-scale seed production that enabled farming to satisfy an increasing international market demand for 'white fish' as wild sourced seed were limited in supply. Fish were traditionally fed trash fish and rice bran in wooden cages, later also in pens alongside the river but most production is now in pellet-fed ponds. Air-breathing striped catfish is stocked at high densities of 10-20 individual 10-15 cm fingerlings/m² in 1.5-6.0 m deep earthen ponds, mostly converted from rice fields. Pond water is exchanged daily in the second half of the culture cycle at 20-30% of pond water volume with the Mekong River. Yields 0.8-1.5 kg fish after 8 months of culture are up to 400-600 tonnes/ha/crop. Striped catfish products are exported mostly as frozen fillets, to over 80 countries and territories and there are more than 40 value added products for domestic and international markets.

Striped catfish farming is becoming increasingly vertically integrated with most of the recent striped catfish farmers being investors from other sectors as it requires a high level of investment, over US\$200,000/ha (Belton et al., 2011). Due to the increasing demand for high quality striped catfish fingerlings, a number of large-scale grow-out farms have built hatcheries to produce their own seed. Most processing factories also have their own large farms which supply the bulk of their fish with the result that smaller independent farmers may not be able to sell their fish when there is a market glut. About 30% of striped catfish farms stopped producing in 2009, mostly smaller-scale farms.

There are concerns about the sustainable intensification of striped catfish culture in Vietnam. While pond effluents are either pumped out or flushed by tidal action into the Mekong River, there has been little to no adverse environmental impact on the main river (Anh et al., 2010; De Silva et al., 2010; Bosma et al., 2011) although there are localised adverse impacts in small lateral canals and channels (Nguyen, T.P and B. Belton, personal communication). It has been estimated that the combined waste emissions from striped catfish production and processing account for less than 1% of the total suspended solids, nitrogen and phosphorus loads in the Mekong River, most of which come from agriculture, industry and human settlements (Anhet et al., 2010). Although striped catfish farming appears to be within the carrying capacity of the Mekong River and the South China Sea, BMPs are being introduced to the striped catfish sector in Vietnam (NACA et al., 2011), including attempts to manage sludge that accumulates on the pond bottom during the culture cycle and must be periodically removed (Boyd et al., 2011).

Bangladesh

There has been a recent rapid development of intensive pond culture of striped catfish in the Greater Mymensingh area of Bangladesh as the species can be stocked in ponds at a much higher density than carps while maintaining a fast growth rate using both farm-made and increasingly industrially manufactured pelleted feed (Ahmed, 2007; Ahmed and Hassan, 2007; Edwards and Karim, 2007). A recent survey of striped catfish farming in Bangladesh revealed a mean productivity of 40 tonnes/ha with 88% of farms producing a range of 15-65 tonnes/ha of catfish with an additional 10-20% of Chinese and Indian major carps and Nile tilapia (Ali et al., 2013). The average annual yield of striped catfish of 40 tonnes/ha is many times greater than that of about 3 tonnes/ha for carps. When commercial farming of striped catfish started the profit was very high as the public initially confused the species with a rich man's fish, the scarce native catfish *Pangasius pangasius* which retails for \$4-6/kg as attempts to develop its commercial culture have been unsuccessful.

Striped catfish yields in Bangladesh are much less than in Vietnam as ponds are shallow with a depth of only 1.5 m as they have been constructed in low-lying rice land areas; draining would not be possible if they were deeper. Large commercial farms are filled with groundwater pumped from 100m deep tube wells with one third of the pond water volume changed ever 10-15 days to maintain water quality. Fifty gram nursed fingerlings are stocked at 4-5/m² and are fed with agro-industrially manufactured pelleted feed at a FCR of 1.7-1.8. The average production is 60-70 tonnes/ha of 1.0-1.2 kg sized fish in 10 months, including the cool season with limited growth. Production on small-scale farms is less, about 40 tonnes/ha, as they use either farm-made minced or small-scale factory produced pellets with low stability and mostly have static unchanged water. These two factors cause poor water quality, leading to poorer quality fish suitable only for the local market.

Total production of striped catfish reached 300,000 tonnes in 2008 which caused a market glut and fall in farm gate price below the cost of production and about 30% of farmers stopped raising the fish. The fish retails for just over \$1.00/kg making it one of the cheapest fish on the local market, comparable in price to silver carp and therefore of importance for national food security

India

Striped catfish production has increased dramatically in India over the last few years, especially in Andhra Pradesh as it has higher production and profit than Indian major carps (R. Rama Krishna, personal communication; Anon, 2011). The pond area in Andhra Pradesh increased from 4,500 ha in 2006 to 32,000 ha in 2010, with total production an estimated 0.64-0.80 million tonnes. Production in pellet-fed ponds is 20-25 tonnes/ha, much higher than the 8-10 tonnes/ha for carps, and made possible by the availability and use of commercial pelleted feed. Striped catfish farmers either switched from farming carps, used abandoned shrimp ponds with access to freshwater or constructed new ponds.

Myanmar

Striped catfish is currently farmed in limited quantity in static water ponds in Myanmar in polyculture with rohu and other carps and tilapia, or in monoculture. However, there is huge potential to considerably increase production of striped catfish in the country as the Ayeyarwaddy Delta has abundant water like the Mekong Delta but unlike Vietnam, Myanmar has large areas of land that could be used to grow soybean for inclusion in pelleted feed (Edwards, 2009b).

Culture-based fisheries

There is an estimated 67 million ha of small water bodies constructed mainly for irrigation in Asia so there is huge potential for increased fish production through responsible fish stock enhancement (De Silva, 2003). Community or culture-based fisheries (CBF), a type of extensive aquaculture in small water bodies, has been described as an 'underutilised opportunity in aquaculture development'. While there is increasing need for intensification of aquaculture production to meet the growing demand for fish, production of more fish from existing waters with minimal external feed inputs provides an important means to augment conventional aquaculture practices. Thus, there is a vast area of open waters in Asia that offer considerable potential to increase production of fish from food.

A specific technical issue is the need to stock large fingerlings to minimise stocked seed being consumed by wild carnivorous fish which requires attention to nursing fry to more predator-resistant large fingerlings prior to stocking. While technically simpler than conventional aquaculture, the promotion of CBF is likely to deliver more immediate yield increases than the investment in technology of intensive approaches such as breed and feed and improvement. However, there are invariably complex technical, social and institutional issues regarding biodiversity, access to water bodies, social equity arrangements, and competition of water use as discussed in a monograph entitled 'Better-practice approaches for culture-based fisheries development in Asia' (De Silva et al., 2006).

Aquatic macrophytes

It is well known that fish are important in national food security in many Asian countries but the considerable role that aquatic plants such as water spinach (*Ipomoea aquatica*) and water mimosa (*Neptunia oleracea*) play in food security is less well appreciated (Edwards, 2009). Water spinach is inexpensive, provides high-quality protein, minerals and vitamins and is easy to digest; all parts of the plant, the stem, leaves and especially the young apex, can be consumed. Considerable quantities of edible aquatic plants are cultivated in Asia but their production and value are not recorded in the annual FAO statistics for aquaculture production despite creating income and employment for a significant number of especially peri-urban households, and in many cases recycling and treating urban waste water while producing a green and nutritious foodstuff consumed on a daily basis by millions of people (PAPUSSA, 2006). This is presumably because freshwater aquatic macrophytes 'fall between two stools', being neglected by agronomists as they are aquatic and not terrestrial plant crops and by aquaculturists, a zoologically dominated profession, because they are not animals although seaweed production and values are recorded.

Water spinach in Phnom Penh, Cambodia, is mostly grown in floating beds secured by stakes by poor communities on the surface of a lake close to where the main city sewage is discharged untreated into the lake. It accounts for nearly half of the total sales of fresh vegetables in the city. Poor households benefit from farming aquatic plants but they are often affected by wastewater related skin conditions from daily contact with wastewater in the lake although research has indicated that well-cooked aquatic vegetables do not pose a health risk to consumers. As the low-lying natural water bodies around the city where aquatic plants are farmed are threatened by an expanding city and increasing numbers of factories and industries around the lake, the future livelihood of the people who live around and depend on the lake is uncertain.

Over 80% of total production of water spinach in Thailand, estimated at almost 60,000 tonnes, is produced in the central plain areas around Bangkok. Most is produced in former rice fields with inorganic fertilisers.

A manual for the cultivation of four most commonly cultivated aquatic plants in and around four cities in South East Asia (water spinach; water mimosa; water dropwort, *Oenanthe stolonifera*; and water cress, *Rorippa nasturtium-aquaticum*) has been published (PAPUSSA, 2006).

Small-scale farmer livelihoods

Diversification

While there is a need for intensification of aquaculture through technology there is also need for more widespread dissemination of existing aquaculture practices, especially to diversify the livelihoods to improve the welfare of millions of small-scale farmers who dominate aquaculture by farm number if not in total production in developing countries. However, there is a need to consider that many aquaculture practices that may be regarded as sustainable on today's scale may not be so when conducted on a much larger scale without proper site selection and the introduction of BMPs.

Many less intensive systems provide an opportunity to produce food mainly for household consumption, and possibly for some income, with less risk. Less intensive systems may also be the best entry point for potential new entrant small-scale farmers or fishers, the 'first step on the ladder of intensification to farm fish' before they decide if they want to intensify for aquaculture to provide a significant income as they are relatively low cost and have a lower risk (Edwards, 2009; Edwards, 2010a). Traditional small-scale IAAS usually have such a low resource base that in most cases aquaculture in rice fields and ponds provides mainly household subsistence although this may provide small but significant contributions towards relatively poor farming household nutrition and income. Farmers throughout the developing world are increasingly motivated to raise fish for income rather than for household subsistence so for aquaculture to become a more meaningful livelihood option for small-scale farmers through increased income from sale of fish, there is a need to intensify fish production. Farmers need to intensify aquaculture to become a small to medium enterprise (SME) to provide significant household income. Intensification could

be achieved by either indirect integration using off-farm fertilisers such as feedlot poultry manure and supplementary feeds such as brans and oil cakes or by using pelleted feed.

Thirty three successful case studies of small-scale aquaculture (SSA), including both grow-out and seed production, were presented at the Expert Workshop on Enhancing the Contribution of Small-Scale Aquaculture (SSA) to Food Security, Poverty Alleviation and Socio-Economic Development, to illustrate their contributions to poverty alleviation, economic growth and rural development (Edwards, 2010b). The case studies include a range of different production systems, both grow-out and seed, from inland and coastal areas, and from diverse agro-ecological and natural ecological, social and economic contexts. The case studies indicate major social benefits from SAA in many countries in Asia although much fewer and to a lesser degree in Africa and Latin America and the Caribbean. However, it is clear that SSA plays a major role for relatively poor households in many countries in the three regions and has potential to continue to do so and expand and/or sustainably intensify in both inland and coastal areas. There is huge potential for the expansion of SSA, especially in lesser developed Asian countries. As small-scale farms become SMEs, they would also be able to contribute more to national food security which they are unable to do to a significant extent because of their current low level of production.

An excellent example of the successful introduction and extension of small-scale IAAS is provided by Bangladesh. Studies have clearly demonstrated that the uptake of improved aquaculture practices has had a significant and positive impact on the welfare of low-income and resource-poor households through improved family nutrition and income (ADB, 2003; Murshed-e-Jahanet al., 2009). Borrow pits and derelict ponds had extensive production of < 1 tonne/ha as the only input was usually seed. Project interventions tripled production to at least 3 tonnes/ha by stocking large fingerlings and fertilising and feeding with on-farm (direct IAA) and local off-farm manures, brans and oil cakes (indirect IAA). Important introductions of exotic fish to the traditional polyculture of indigenous Indian major carps were grass carp fed with on-farm vegetation such as grass, banana leaves and duckweed, and filter-feeding silver carp which grows rapidly in green water ponds and comprises a major part of the harvest. Bangladeshi IAAS are relatively simple compared to the traditional pond IAAS of China and Vietnam as monogastric livestock (pigs and poultry) are not commonly raised on or near the pond; nor are vegetables commonly raised on pond dikes although cultivation of dike crops has developed recently in some areas (Ahmed et al., 2007; Edwards, 2007). However, while some relatively better-off rice farmers have become SME's in Bangladesh through converting rice fields to intensive striped catfish and tilapia ponds, many others previously had professions other than farming crops or fish such as school teachers and business (B. Belton, personal communication). There are numerous cases of small-scale farmers with a small fish pond on a crop-dominated farm developing aquaculture into a SME in other countries in Asia although they have rarely been documented.

Small-scale seed production

Small-scale farmers are increasingly involved in nursing to produce fingerlings as aquaculture becomes more specialised and segmented. Hatchery is usually a highly

specialised business carried out by better-off skilled farmers although there are small-scale hatcheries for both inland and coastal species e.g., small-scale marine finfish hatcheries in Indonesia; and small-scale prawn and shrimp hatcheries in Thailand. However, even small-scale hatcheries are most likely owned by a small number of better-off skilled farmers. Such small-scale hatcheries usually do not hold and induce broodstock to breed but purchase fertilised eggs or newly hatched fry or larvae from larger hatcheries and so they should more correctly be considered as nurseries rather than hatcheries.

Nursing maybe a more appropriate and profitable livelihood option than low-input grow-out for small-scale farmers as it requires less skill than hatchery, has a short production cycle and involves less risk, as well as has having lower investment and better cash flow than grow-out. Small-scale farmers may be unable to afford the considerable increase in expenditure associated with intensification of grow-out through increased stocking density of seed and increased feed requirement. Large-scale hatcheries in some countries have linked up with small-scale farmers to nurse fry or larvae because of the large area of land needed for nursing and the more profitable production for hatcheries of larger numbers of fry or larvae than fingerlings or post-larvae.

Decentralised seed production of species that readily breed without hormone treatment such as common carp and tilapia has been successfully introduced to small-scale farmers in areas remote from large-scale hatcheries in well-endowed and more central areas for aquaculture, especially in Bangladesh (Barman and Little, 2006; Barman et al., 2007).

Many Aceh, Indonesia farmers nurse grouper fry to fingerlings because it is profitable and the short nursing period of 30-50 days reduces risk of loss due to disease (Komarudin et al., 2010). Large-scale hatcheries which produce the fry are keen to sell them as soon as possible to make space for further production and grow-out farms do not have nursing facilities so a specialised nursery business has developed that is attractive to small-scale farmers in Aceh and East Java comprising 5,000 such operations in Aceh alone.

Extensification

Although it would appear to offer clear-cut benefits in terms of conventional economic rationality, even quite limited intensification may not be an attractive option for many small-scale farming households that cannot afford to take risk (Belton and Little, 2011). Small ponds close to the homestead are widespread in rural Bangladesh; a tendency towards risk aversion and ensuring basic household food security through growing rice is supported by the low opportunity costs of extensive fish production which also provides fish for household consumption at minimal cost.

The risk of losing shrimp crops through flooding and disease also leads many small-scale households in coastal areas of both Bangladesh and Vietnam to maintain less intensive shrimp culture systems (Belton and Little, 2011). Many small-scale farmers in both countries are unwilling to take the risk of intensifying production through higher stocking and feeding rates to potentially earn much higher profits because they cannot afford the risk of high shrimp mortalities which occur frequently due to outbreaks of shrimp diseases. Furthermore, resilience may also be increased by diversification through

polyculture with fish and other aquatic organisms, either stocked intentionally or allowed to enter the shrimp pond during tidal exchange of water, rather than farming an intensified monoculture of shrimp as carried out by wealthier shrimp farmers. Diversification may also involve rotation of rice and shrimp, with shrimp also proven to be less disease-prone in farms with alternation of crops compared to successive crops of shrimp monoculture.

Conclusions

There is a major trend towards intensification and use of formulated pelleted feed in aquaculture and even herbivorous and omnivorous species that are traditionally considered to be relatively low-input species such as grass carp and tilapia are increasingly being fed pellets rather than being raised in semi-intensive integrated farming systems (Edwards, 2009, 2011). The main driver for intensification once there is a market is farm profit because in economic terms there is greater money to be made per farm from intensive aquaculture even though the cost of production as well as the adverse environmental impacts are both larger than in semi-intensive aquaculture which characterises most integration. As stated by Bostock (2010), 'a widespread return to low-intensity production is unlikely to be an acceptable option'.

There does not appear to be any 'magic bullet' or panacea on the horizon although promising aquaculture practices for sustainable intensification such as the 80:20 polyculture system, low-volume high-density cage culture and the cage-in-pond system are likely to become increasingly important. Aquaculture practices currently receiving considerable attention such as aquaponics, biofloc and IMTA are unlikely to make a significant contribution to future global fish supplies.

It has often been stated that the future of aquaculture lies in the oceans because of perceived constraints of land and freshwater. Although the writer was involved in the preparation of the initial drafts of the FAO EAA guidelines, he does not agree with the following quotation from the background to the guidelines: 'experts agree that most of the future aquaculture expansion will occur in the seas and oceans, certainly further offshore, perhaps even as far as the high seas' (FAO, 2010). Is this realistic or futuristic dreaming? While offshore seas and the open ocean have virtually unlimited potential for flushing and natural treatment of wastes from aquaculture cages as well as high water quality for culture, major technological, operational, political and especially economic challenges remain to be resolved before the oceans could become a major supplier of farmed fish. While major aquaculture companies may eventually be able to farm fish offshore economically, it is highly unlikely that smaller operators would ever be able to do so.

A future increase in fish production is most likely to be provided by more widespread dissemination of current aquaculture practices although with further implementation of BMPs and the EAA to improve existing systems and to better integrate aquaculture into inland watersheds and coastal zones. The culture of currently farmed major species groups such as carps, tilapias and striped catfish has great potential for expansion in ponds, including conversion of low yielding rice lands to ponds in countries where aquaculture is underdeveloped and rice field conversion has not reached a level at which there is concern to about declining production

of cereals. Culture-based fisheries in reservoirs and cultivation of aquatic macrophytes both have considerable potential for expansion.

The definition of sustainable intensification of aquaculture should be broad to include not only the sustainable intensification of production of aquaculture practices from a unit area or volume of water in a given culture system but also the diversification of small-scale farmer livelihoods to include aquaculture if this leads to a sustainable increase in farm household welfare. While production from traditional IAAS systems has declined considerably in well-endowed aquaculture areas, especially in China where they were dominant until relatively recently, integrated systems still have a role to play in densely populated rural areas, especially those in remote areas with limited livelihood opportunities. While rice/fish culture has limited overall potential, rice/freshwater prawn culture has expanded considerably in low-lying rice lands in Bangladesh and Vietnam. It should also be recognised that farmers may choose to maintain a low intensity of production or reduce the intensity of production of their aquaculture system (extensification rather than intensification) if these contribute to a more sustainable overall livelihood portfolio.

Acknowledgements

Nesar Ahmed, Ben Belton, Roel Bosma, Claude Boyd, Stuart Bunting, Michael Cremer, Thierry Chopin, James Diana, John Hargreaves, Le Thanh Luu, David Little, Amir Neori, Mike Rimmer, Simon Funge-Smith, Miao Wei Min, Lukas Manomaitis, Francis Murray, Nguyen V.Hao, James Rakocy, Sena De Silva, Tran Ngoc Hai, Max Troel, Zhang Wenbo and Zhou En Hua for discussion and provision of information and documentation. Ben Belton and Stuart Bunting are thanked in addition for a critical review of the manuscript.

References

- Abery N.W., Sukadi F., Budhiman A.A., Kartamihardja E.S., Koeshendrajana S., Buddhiman and De Silva S.S. 2005. Fisheries and cage culture of three reservoirs in West Java, Indonesia; a case study of ambitious developments and resulting interactions. *Fisheries Management and Ecology* 12: 315-330.
- ADB.2005. An Evaluation of Small-scale Freshwater Rural Aquaculture Development for Poverty Reduction. Operations Evaluation Department, Asian Development Bank, Manila, Philippines. 164 pp.
- Ahmed, N. 2007. Economics of aquaculture feeding practices: Bangladesh, pp. 33-64. In: M.R. Hasan (ed.), Economics of aquaculture feeding practices in selected Asian countries. FAO Fisheries Technical Paper 505, FAO, Rome.
- Ahmed, N., H. Demaine and J.F. Muir. 2008. Freshwater prawn farming in Bangladesh: history, present status and future prospects. *Aquaculture Research* 39 (8): 806-819.
- Ahmed, N., and S.T. Garnett. 2010. Sustainability of freshwater prawn farming in rice fields in southwest Bangladesh. *Journal of Sustainable Agriculture* 34 (6): 659-679.
- Ahmed, N., and M.R. Hasan. 2007. Growing pangas industry faces constraints in Bangladesh. *Global Aquaculture Advocate* 10(3):60-62.
- Ahmed, N., and M. Troell. 2010. Fishing for prawn larvae in Bangladesh; an important coastal livelihood causing negative effects on the environment. *Ambio* 39 (1): 20-29.
- Ahmed, N., M.A. Wahab, and S.H. Thilsted. 2007. Integrated aquaculture-agriculture systems in Bangladesh : potential for sustainable livelihoods and nutritional security of the rural poor. *Aquaculture Asia* 12(1):33-41.
- Ahn, P.T., C. Kroeze, S.R. Bush and A.P.J. Mol. 2010. Water pollution by *Pangasius* production in the Mekong Delta, Vietnam: causes and options for control. *Aquaculture Research* 42 (1): 108-128.

- Ali, H., M. M. Haque and B. Belton. 2013. Striped catfish (*Pangasianodon hypophthalmus*, Sauvage, 1878) aquaculture in Bangladesh: an overview. *Aquaculture Research* 44: 950-965.
- Anon, 2011. Pangasius catfish in India, moving forward with better management and fillet processing. *AQUA Culture Asia Pacific Magazine* May/June, pp.26-29.
- Avnimelech, Y. 2011. Tilapia production using biofloc technology. Saving water, waste recycling improves economics. *Global Aquaculture Advocate* May/June, pp.66-68.
- Avnimelech, Y. 2012. *Biofloc Technology*. Second Edition. World Aquaculture Society.
- Avnimelech, Y., M. Kochva, and S. Diab. 1994. Development of controlled intensive aquaculture systems with a limited water exchange and adjusted carbon to nitrogen ratio. *Bamidgeh* 46(3):119-131.
- Azim, M.E., and D.C. Little. 2006. Intensifying aquaculture production through new approaches to manipulating natural food. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 2006, No. 062. 23 pp. Available at <http://www.cababstractsplus.org/cabreviews>.
- Barman, B.K., and D.C. Little. 2006. Nile Tilapia (*Oreochromis niloticus*) seed production in irrigated rice-fields in Northwest Bangladesh – an approach appropriate for poorer farmers? *Aquaculture* 261:72-79.
- Barrington, K., T. Chopin and S.M.C. Robinson. 2009. Integrated multi-trophic aquaculture (IMTA) in marine temperate waters, pp. 7-46. In D. Soto (ed.), *Integrated mariculture: a global review*. FAO Fisheries and Aquaculture Technical Paper No. 529, FAO, Rome.
- Belton, B et al., 2011. Review of aquaculture and fish consumption in Bangladesh. *Studies and reviews 2011-53*. WorldFish Center, Penang.
- Belton, B., and D. Little. 2008. The development of aquaculture in Central Thailand: domestic demand versus export-led production. *Journal of Agrarian change* 8(1): 123- 143.
- Belton, B., and Little, D.C. 2011. Contemporary visions for small-scale aquaculture, pp. 151-170. In: Chuenpagdee, R. (ed.) *Contemporary visions for world small-scale fisheries*. Eburon, Delft.
- Belton, B., D.C. Little and L.X. Sinh. 2011. The social relations of catfish production in Vietnam. *Geoforum* 42 (5): 567-577.
- Belton, B., D. Little and J. Young. 2006. Red tilapia cage culture in Central Thailand. *Aquaculture Asia* 11 (3): 28-30.
- Bosma, R., P.T. Anh and J. Potting. 2011. Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. *International Journal of Life Cycle Assessment* 16 (9): 903-915.
- Bosma, R.H., and M.C.J. Verdegem. 2011. Sustainable aquaculture in ponds: principles, practices and limits. *Livestock Science* 139: 58-64.
- Bostock, J. 2010. Foresight Project on global food and farming futures. The application of science and technology development in shaping current and future aquaculture production systems. *Journal of Agricultural Science*, pages 1-9, doi:10.1017/S0021859610001127.
- Bostock, J., B. Mc Andrew, R. Richards, K. Jauncey, T. Telfer, K. Lorenzen, D. Little, Lindsay Ross, Neil Handisyde, I. Gatward and R. Corner. 2010. *Aquaculture global status and trends*. *Phil. Trans. R. Soc. B* 365:2897-2912.
- Boyd, C. E., and S. Chainark. 2009. Advances in technology and practice for land-based aquaculture systems: ponds for finfish production, pp. 984-1009. In: G. Burnell and G. Allan (eds.), *New technologies in aquaculture, improving production efficiency, quality and environmental management*. Woodhead Publishing Ltd., Cambridge, UK.
- Boyd, C.E., F. Rajts and J. Firth. 2011. Sludge management at BAP Pangasius farm cuts TAN, BOD5, TSS in discharges. *Global Aquaculture Advocate* September/October, pp. 40, 42, 44.
- Boyd, C.E., C. Tucker, A. McNiven, K. Bostock and J. Clay. 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. *Reviews in Fisheries Science* 15: 327- 360.
- Bremerhaven Declaration. 2013. *Bremerhaven Declaration on the Future of Global Open Ocean Aquaculture*. <http://ecologicalaquaculture.org/welcome/2013/01/26/bremerhaven-declaration-on-the-future-of-global-open-ocean-aquaculture/>
- Bunting, S.W. 2013. *Principles of sustainable aquaculture, promoting social, economic and environmental resilience*. Routledge, Abingdon, UK. 301 pp.
- Bunting, S.W., and M. Shpigel. 2009. Evaluating the economic potential of horizontally integrated land-based marine aquaculture. *Aquaculture* 204: 43-51.
- Chambers, M.D. et al., 2011. Small-scale, submersible fish cages suitable for developing economies. *Global Aquaculture Advocate* January/February, pp. 30-32.
- Chopin, T., J.A. Cooper, G. Reid, S. Cross and C. Moore. 2012. Open-water integrated multitrophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture* 4: 209-220.
- Chopin, T., M. Troell, G.K. Reid, D. Knowler, S.M.C. Robinson, A. Neori, A.H. Buschmann and S.J. Pang. 2010. Integrated multi-trophic aquaculture. Part 11. Increasing IMTA adoption. *Global Aquaculture Advocate* November/December, pp.17-19.
- De Silva, S.S. 2003. Culture-based fisheries: an underutilised opportunity in aquaculture development. *Aquaculture* 221: 221-241.
- De Silva, S. 2012. Aquaculture - a newly emergent food production sector- and perspectives of its impacts on biodiversity and conservation. *Biodiversity Conservation* DOI 10.1007/s10531-012-0360-9.
- De Silva, S.S., U.S. Amarasinghe and T.T.T. Nguyen. 2006. Better-practice approaches for culture-based fisheries development in Asia. Australian Centre for International Agricultural Research, Canberra. 96 pp.
- De Silva, S.S., B.A. Ingram, P.T. Nguyen, T.M. Bui, G.J. Gooley and G.M. Turchini. 2010. Estimation of nitrogen and phosphorus in effluent from the striped catfish farming sector in the Mekong Delta, Vietnam. *Ambio* 39 (7): 504-514.
- De Silva, S.S., and N.T. Phuong. 2011. Striped catfish farming in the Mekong Delta, Vietnam: a tumultuous path to a global success. *Reviews in Aquaculture* 3 (1): 45-73.
- Diana, J.S., C.K. Lin and Y. Yi. 1994. Supplemental feeding of tilapia in fertilised ponds. *J. World Aquaculture Society* 25 (4):497-506.
- Diana, J.S., C.K. Lin and Y. Yi. 1996. Timing of supplemental feeding for tilapia production. *J. World Aquaculture Society* 27 (4): 410-419.
- Edwards, P. 2004. Traditional Chinese aquaculture and its impact outside China. *World Aquaculture* 35(1):24-27.
- Edwards, P. 2007. Diversification of rice farming alleviates poverty in a Bangladesh village. *Aquaculture Asia* 12(2):18-20.
- Edwards, P. 2008. Comments on possible improvements to carp culture in Andhra Pradesh. *Aquaculture Asia* 13 (3): 3-7
- Edwards, P. 2009a. Traditional Asian aquaculture: definition, status and trends, pp.1029-1063. In: G. Burnell and G. Allan (eds.), *New technologies in aquaculture, improving production efficiency, quality and environmental management*. Woodhead Publishing Ltd., Cambridge, UK.
- Edwards, P. 2009b. Myanmar revisited. *Aquaculture Asia* 14 (1): 3-12.
- Edwards, P. 2010a. Review of small-scale aquaculture: definitions, characterization, numbers. Background paper presented at the Expert Workshop on Enhancing the Contribution of Small-Scale Aquaculture (SSA) to Food Security, Poverty Alleviation and Socio-Economic Development, 21-24 April 2010, Hanoi, Viet Nam.
- Edwards, P. 2010b. Successful SSAs and their contribution to economic growth at the national level and poverty alleviation and rural development at the local level. Background paper presented at the Expert Workshop on Enhancing the Contribution of Small-Scale Aquaculture (SSA) to Food Security, Poverty Alleviation and Socio-Economic Development, 21-24 April 2010, Hanoi, Viet Nam.
- Edwards, P. 2011. Recent developments and future prospects of inland aquaculture in Asia. *Aquaculture Asia* 16(1): 3-10
- Edwards, P. 2013. The EU-funded project 'Sustainable and Ethical Aquaculture Trade'(SEAT) in China. *Aquaculture Asia* 18: 3-14.
- Edwards, P., and M. Karim. 2007. Evolution of polyculture in Bangladesh. *Global Aquaculture Advocate* 10(1):57-59.
- Edwards, P., C.K. Lin and A. Yakupitiyage. 2000. Semi-intensive pond aquaculture, pp. 377-403. In: M. Beveridge and B.J. McAndrew (eds.), *Tilapias: biology and exploitation*. Chapman and Hall.

- Fang, J.G., and L.H. Lui. 2013. Large scale coastal and offshore integrated multi-trophic aquaculture (IMTA). <http://www.asemaquaculture.org/files/7%20Liu%20Hui.pdf>. Accessed 3 July 2013.
- Fang, J. G., J.H. Zhang, Z.J. Jiang, Z.H. Qi and J. Funderud. 2013. Development of multi-trophic aquaculture in Sungo Bay, China. http://pemsea.org/eascongress/international.../presentation_t5-1_fang.pdf. Accessed # July 2013.
- Fang, X.Z. 2003. Rice-fish culture in China. *Aquaculture Asia* 8(4):44-46.
- FAO. 2010. *Aquaculture Development, 4. Ecosystem approach to aquaculture. FAO Technical Guidelines for Responsible Fisheries 5, Supplement 4*. FAO, Rome. 53 pp.
- FAO. 2011. *Save and grow, a policy maker's guide to the sustainable intensification of smallholder crop production*. FAO, Rome.
- Fredheim, A., and R. Langan. 2009. Advances in technology for off-shore and open ocean fish aquaculture, pp. 914-944. In: G. Burnell and G. Allan (eds.), *New technologies in aquaculture, improving production efficiency, quality and environmental management*. Woodhead Publishing Ltd., Cambridge, UK.
- Gal, D., P. Szabo, F. Pekar and L. Varadi. 2003. Experiments on the nutrient removal and retention of a pond recirculation system. *Hydrobiologia* 506-509:767-772.
- Godfray, H.C., et al. 2010. Food security: the challenge of feeding 9 billion people. *Science* 327: 812- 818.
- Halwart, M. 2006. Biodiversity and nutrition in rice-based aquatic ecosystems. *Journal of Food Composition and Analysis* 19:747-751.
- Halwart, M., and M.V. Gupta. 2004. *Culture of fish in rice fields*. FAO, Rome and the WorldFish Center, Penang, 83 pp.
- Hambrey, J., B. Belton and P. Edwards. 2008. An ecosystem approach to freshwater aquaculture: a global review, pp.117-173. In: D. Soto, J. Aguilar-Majarrez and N. Hishamunda, *Building an ecosystem approach to aquaculture. FAO Fisheries and Aquaculture Proceedings 14*, FAO, Rome.
- Haque, M.M., D.C. Little and B. K. Barman. 2010. The adoption process of ricefield-based fish seed production in Northwest Bangladesh: an understanding through quantitative and qualitative investigation. *The Journal of Agricultural Education and Extension*. 16(2):161-177.
- Hargreaves, J.A. 2012. Book review. *Biofloc technology, Second Edition* by Yoram Avnimelech. *World Aquaculture* 43 (20): 66,68.
- Hargreaves, J.A. 2013. *Biofloc production systems for aquaculture*. SRAC Publication No. 503, Southern Regional Aquaculture Center, United States Department of Agriculture and National Institute of Food and Agriculture. 11pp.
- Kapetsky, J.M., J. Aguilar-Manjarrez. 2012. A global assessment of offshore mariculture potential from a spatial perspective. Abstract, AQUA 2012, World Aquaculture Society, Prague, Czech Republic.
- Komarudin, U., M.A. Rimmer, Islahuttaman, Zaifuddin and S. Bahrawi. 2010. Grouper nursing in Aceh, Indonesia. *AQUA Culture Asia Pacific Magazine*, March/April, pp. 21-25.
- Langan, R. 2009. Opportunities and challenges for off-shore farming, pp. 895-913. In: G. Burnell and G. Allan (eds.), *New technologies in aquaculture, improving production efficiency, quality and environmental management*. Woodhead Publishing Ltd., Cambridge, UK.
- Lin, C.W. 1990. Integrated culture of walking catfish (*Clarias macrocephalus*) and tilapia (*Oreochromis niloticus*), pp. 209-212. In: R. Hirano and I. Hanyu (eds.), *The Second Asian Fisheries Forum*, Asian Fisheries Society, Manila.
- Liping, L., K. Hayse-Gregson, J. S. Diana, W. M. Wang , B. Y. Song and Z.W. Wu. 2012. Impacts of integrated cage culture system on water quality in deep water lakes. Abstract. *World Aquaculture Society, Prague*.
- Manomaitis, L., and M.C. Cremer. 2007. Demonstrating the American Soybean Association Internal Marketing Program's aquaculture technologies developed in China in the Southeast Asian and Asian Subcontinent regions through the Soy in Aquaculture Project. Abstract, *Asian-Pacific Aquaculture 07, August 5-8, Hanoi, Vietnam. Asian Pacific Chapter, World Aquaculture Society* p. 185.
- McIntosh, R. 2008. Advancing shrimp farm technologies support greater efficiencies, sustainability. *Global Aquaculture Advocate* September/October, pp.88-90.
- Milstein, A. 2005. Polyculture in aquaculture. *Animal Breeding Abstracts* 73(12):15 N-41N.
- Murray, F.J. and D.C. Little. 2011. Comparative performance of commercial scale tilapia culture using biofloctechnology (BFT) and recirculating aquaculture system (RAS). Abstract, *Asian Pacific Aquaculture 2011*, World Aquaculture Society, Kochi, India.
- Murshed-e-Jahan, K., M. Ahmed and B. Belton. 2009. The impacts of aquaculture development on food security: lessons from Bangladesh. *Aquaculture Research*, 1-15.
- NACA et al., 2011. Better management practices for the striped catfish farming sector in the Mekong Delta, South Vietnam. http://library.enaca.org/inland/catfishbmps/catfish_bmp_v2.pdf
- Nandeesha, M.C. 2001. Andhra Pradesh farmers go in to revolutionary carp research. *Aquaculture Asia* 4(4):29-32.
- Nandeesha, M.C. 2003. The "gher revolution". *Innovations in freshwater prawn farming by Bangladesh farmers. Aquaculture Asia* 8(4):31-36.
- Nandeesha, M.C. 2004. Rice-fish culture for food and environmental security. *Aquaculture Asia* 9(3):9-16.
- Navarrete-Mier, F., C. Sanz-Lazáro and A. Martín. 2010. Does bivalve mollusc polyculture reduce marine fin fish farming environmental impact? *Aquaculture* 306: 101-107.
- Nguyen, T.P., T.T.H. Do and N.H. Tran. 2012. Giant freshwater prawn *Macrobrachium rosenbergii* farming in Vietnam - a development within a decade. Abstract, AQUA 2012 - Prague, World Aquaculture Society, Prague.
- Nguyen T.P., N.H. Tran, T.T.H. Tran, V.B. Tran, T.T.H. Do, N.S. Vu, Y. Morooka, Y. Fukuda and M.N. Wilder. 2006. Current status of freshwater prawn culture in Vietnam and the development and transfer of seed production technology. *Fisheries Science* 72:1-12.
- Nguyen, V.H. 2006. Status of catfish farming in the delta. *Catch and Culture* 12(1):13-14.
- PAPUSSA. 2002. A users' manual for the cultivation of commercially important edible aquatic plants in and around 4 cities in SE Asia. Production in aquatic peri-urban systems in Southeast Asia, University of Stirling, Stirling, UK. 78 pp. online at www.papussa.org
- Pretty, J., et al., 2010. The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability* 8 (4): 219-236.
- Rakocy, J.E. 2007. *Aquaponics: integrating fish and plant culture*, pp. 767-822. In: M.B. Timms and J. M. Ebeling, Eds., *Recirculating aquaculture*, North Eastern Regional Center Publication No. 01-007, United States Department of Agriculture.
- Rakocy, J.E., M. P. Masser and T.M. Losordo. 2006. *Recirculating aquaculture tank production systems: aquaponics – integrating fish and plant culture*. SRAC Publication No. 454, Southern Regional Aquaculture Center, United States Department of Agriculture. 16 pp.
- Ramakrishna, R. 2007. Kolleru carp culture in India: an aquaplosion and an explosion. *Aquaculture Asia Magazine* 12 (4): 12-18.
- Reid, G.K., T. Chopin, S.M.C. Robinson, P. Azevedo, M. Quinton and E. Belyea. 2013. Weight ratios of the kelps, *Alaria esculenta* and *Saccharina latissima*, required to sequester dissolved inorganic nutrients and supply oxygen for Atlantic salmon, *Salmo salar*, in integrated multi-trophic aquaculture systems. *Aquaculture* 408-409: 34-46.
- SEAT. Undated. Sustaining the tilapia value chain in China. Poster, Stirling University, UK, led EU Funded Project, 2009-2013. <http://seatglobal.eu/wp-content/uploads/2009/12/China-tilapia-english.pdf>
- Suresh, A.V. 2007. Development of the aqua feed industry in India. Study and analysis of feeds and fertilisers for sustainable aquaculture development. *FAO Fisheries Technical Paper 497*, FAO, Rome, pp. 221-243.
- Taw, N., U. Saleh and B. Slamet. 2013. Malaysia shrimp project scales up for production in biosecure biofloc modules. *Global Aquaculture Advocate* January/February, pp. 44-47.
- Troel, M. 2009. Integrated marine and brackishwater aquaculture in tropical regions: research, implementation and prospects, pp.47-131 In D. Soto (ed.), *Integrated mariculture: a global review*. FAO Fisheries and Aquaculture Technical Paper No. 529, FAO, Rome.

- Troell, C. Halling, A. Neori, T. Chopin, A.H. Buschmann, N. Kautsky and C. Yarish. 2003. Integrated mariculture: asking the right questions. *Aquaculture* 226 (1): 69-90.
- Ye, J.Y. 2002. Carp polyculture system in China : challenges and future trends. In : M. Eleftheriou and A. Eleftheriou (eds.), Proceedings of the ASEM Workshop AQUACHALLENGE, Beijing, April 27-30, 2002.ACP-EU Fish. Res. Rep. 14:27-34.
- Yi, Y. 1999. Modelling growth of Nile tilapia (*Oreochromis niloticus*) in a cage-cum-pond integrated culture system. *Aquacultural Engineering* 21:113-133.
- Yi, Y., and C.K. Lin. 2001. Effects of biomass of caged tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage-cum-pond system. *Aquaculture* 195: 253- 267.
- Yi, Y., C.K. Lin and J.S. Diana. 1996. Influence of Nile tilapia (*Oreochromis niloticus*) stocking density in cages on their growth and yield in cages and in ponds containing the cages. *Aquaculture* 146:205-215.

Culture and breeding of *Archocentrus spilurum* at Tuticorin District of Tamil Nadu, India

Linga Prabu, D.¹ and M. Kavitha²

1. Growel Feeds Pvt. Ltd., Andhra Pradesh, email growelprabu@gmail.com; 2. Aquatic Environment and Management Division, Fisheries College and Research Institute, Tuticorin.

Culture of fresh water ornamental fishes is an important aquaculture activity in Tuticorin District of Tamil Nadu, India. In Tuticorin District there are six large ornamental fish farms and approximately twenty-five small ornamental fish breeders engaged in the business. The culture and breeding of cichlid fish varieties is the main activities of these farms. Tuticorin is the only place in the state where all the important cichlid varieties are cultured and supplied throughout the state and supports an export market as well. Tuticorin has many with salt pans and naturally grown *Artemia* biomass is available for brooders with the only expense for collection. Therefore, culture of cichlid fish varieties is abundant in this area, including Oscar, flower horn, discus, severum, angel fish, red devil, zebra cichlid, fire mouth, frontosa, peacock lemon cichlids, which are actively bred and cultured. A relatively new addition to the area is the blue eyes cichlid.

Blue eyes, *Archocentrus spilurum* is a Central American fish species. It is considered a relatively peaceful cichlid and it is not very fussy when it comes to water conditions and temperature. Among the cichlids, blue eyes are suitable for community tank because of its peaceful nature. It may not be the most colorful, but they are very pretty little fish and their blue eyes set them apart from other cichlids. In nature it prefers shallow areas with sand, mud and rock substrates as well as slow moving waters of the lower riverine valley areas. Hence, vigorous water movements are not necessary in the aquarium. It inhabits the middle and bottom regions of the tank.

Blue eyes have a pinkish-grey body colour with yellow extending from the underside of the mouth through the throat and into the belly. They have a fairly stocky, deep body, with a short, gently sloping forehead ending in a small, pointed, terminal mouth. Also have seven or eight vertical black stripes, often faint in males, on the body. More pronounced are the black spots midway on the body that start just behind the gills and run the length of the body to the tail. A band running from the eye to the corner of the mouth is often present. The dorsal fin has light aqua streaks through it and is tinged light maroon or vivid red colour. The caudal fin is spangled blue close to the caudal peduncle, less towards the



Male blue eyes brooder.

edge. The anal fin is aqua blue in colour. Females are smaller than males. Usually males grow about 12cm and females to around 8 cm. Even though, males can attain a maximum length of 18 cm.

Food and feeding

Blue eyes are an omnivorous fish. They are not most selective about what they eat. They will readily accept *Artemia* biomass, chopped animal flesh, frozen foods (beef heart, spleen and kidney), flake foods and commercial pellet feeds with sufficient quantity of fishmeal (2mm diameter) produced for other aquaculture species. They relish live black worms, blood worms and *Artemia*. They should be fed with twice or three times a day.

Compatibility

Blue eye cichlids can be set up in community tanks with compatible species in a minimum 100 cm tank. They are peaceful and can be kept with similar kind of fishes. This fishes are relatively easy to maintain in aquariums. During breeding season, males may be aggressive towards each other but they will not disturb other fishes in the tank. Blue eyes are suitable for community tanks with nearly any sized fish, although very small and fancy finned species should not to be put together in community tank. Normally blue eyes are introduced in the community tank along with the red devil cichlid (*Amphilophus labiatus*), Salvini Cichlid (*Nandopsis salvini*), blue dolphin cichlid (*Haplochromis moori*), callichthyid armored catfish (*Megalechis personata*), orinoco sailfin catfish (*Liposarcus multiradiatus*), youcatan molly (*Poecilia velifera*), guppy (*P. reticulata*), sword tail (*Xiphophorus helleri*) and fish of the family Pimelodidae (Long-whiskered catfishes).

Water quality maintenance

Like other cichlids fishes, this fish species can be maintained in a cemented culture tank (5m × 4m × 1m). This fish grows best at temperature ranges of 24–32°C. Temperature plays a major role in growth as well as timing and intensity of spawning. The pH may be maintained slightly acidic (6.5) to alkaline (8.0) condition for its better growth and breeding. The tank should be facilitated with sufficient aeration to provide at least 5ppm dissolved oxygen. The fish requires fairly soft water and the hardness should not increase beyond 100 ppm level. The culture tanks should be maintained with less level nitrite and ammonia since blue eyes are also highly susceptible to elevated levels of ammonia particularly unionised ammonia. The culture tank should be provided with plenty of hideouts such as concrete pipes. The best medicine for prevention of any disease is achieved by avoiding overcrowding and sufficient water exchanges from the tank according to needs.

Breeding

Matured males develop a pronounced hump head and also have longer filaments on the dorsal and anal fins. Females have more pronounced black strips on the body and one of these bars will extend into a dark spot located at the dorsal fin. Males are more colorful than females. Spawning occurs very soon after the fish starts displaying breeding coloration. During the time of spawning, the golden yellow throat and belly colour is replaced with jet black and ventral fins too become black. The female loses its stripes and both male and females develop a horizontal striped pattern on their sides. Blue eye cichlids usually form monogamous pairs.

The spawning tank should be provided with small flower pots kept in such a way that it could not roll, laid on its side. Before breeding, the pair engage in body quivering and tail slapping, after these, they start cleaning the flower pot and then start to spawn in it. The female starts laying its eggs on a vertical surface. Usually, it may lay 100–250 eggs. After releasing the eggs both parents may clean off dust particles and any detritus that deposit on the eggs and aerate them using their fins. The eggs hatch after 65–72 hours of incubation. When the eggs have hatched, the fry will feed from their egg sacs and stay closely together to the side of the wall. The fry will



Releasing the yolk sac larvae from a blue eyes brooder.

become free swimming within a week after hatching. By this time, they will be about 5–7 mm in length. Both parents spend their entire time with the young ones during this time.

From a commercial point of view in order to reduce such long parental care, Tuticorin aquariculturists usually remove the pot containing eggs and transfer it to a hatching tank. This practice is followed to increase the number of spawning cycle in a year. Otherwise, the eggs can be removed from pots by applying a locally proven non-sticky herbal formula (pineapple juice along with some other herbal juice) and transfer them to a jar hatchery which is used to incubate the eggs and minimise the space requirements. After hatching the sac fry are transferred to rectangular water trays made of mild steel. As soon as the egg sacs become empty the fry start feeding on the *Artemia* nauplii, fishmeal and powdered flake food. After a certain time they can feed on rotifers, adult *Artemia*, *Daphnia*, *Moina* and small sized crumbles and pellet diets (0.75–1 mm diameter). Regular water exchange is necessary to keep the water quality in good condition, but should not exceed more than 25% of the water per time, since large water exchanges possibly affect the survival of the fry. During water exchange, care has to be taken to use the water of same temperature.

Disease Management

Like other ornamental fishes blue eyes are also susceptible to the following diseases and the following practices are adopted by the innovative farmers of Tuticorin district. Hole in head disease is a disease caused by a protozoan parasite *Hexamita*. The disease is identified by white colour, slimy



The boy working in the farm standing in the blue eyes brooders tank.

faeces and the presence of “hole in the head”. The symptoms of this disease are often confused with similar symptoms of nutritional deficiencies. The disease is treated with common aquarium anti-parasitic agents. Lymphocystis disease is a viral disease. Treatment is difficult and affected fishes should be separated. Dropsy or kidney bloat is a disease caused by one of several gram negative bacteria commonly present in aquarium habitats. As the infection progresses, skin lesions develop, the belly fills with fluids and becomes swollen, internal organs are damaged, and ultimately the fish will die. The disease is difficult to cure but salt treatment may be useful in the initial stages.

Saprolegniasis disease is caused by *Saprolegnia* fungi. The fishes appeared to have a “cotton wool” matted mass growing out of the skin and scales. The fish have to be removed from water and the lesions with an aquarium anti-fungal agent. Argulosis and Lernaeosis are the disease caused by crustacean parasites namely *Argulus* sp. and *Lernaea* sp. respectively. The infected fish rub violently against walls of the cement tank due to irritation. Treat the fish in 1-2% bath of potassium permanganate (KMnO₄) for 15 min bath, and painting the affected region with iodine solution will shows fast remedy.

Market value

Blue eyes, being an exotic fish variety, have been marketed domestically throughout India. In the domestic market it fetches various prices based on its size. It may not be too colorful and being moderate sized fish, a pair has a value of

Rs. 250–450 based on their size and coloration. The consignments are usually transported to Kolkata and Chennai via train routes and sometimes directly exported to Singapore by air from Tuticorin Airport.

Conclusion

Blue eyes as a relatively less aggressive cichlid draw good interest among fish hobbyists that prefer community tanks. Among the culturists at Tuticorin District, blue eyes draws special attention because of their easy breeding nature compared to other cichlid varieties, as well as the easy availability of *Artemia* biomass and adaptability of the fish to commercial carp pellet feed. This is the secret of success for blue eye breeding and culture in Tuticorin area of Tamil Nadu.

References

- Skomal, G., 2001. Setting up a freshwater aquarium: An owner's guide to a happy healthy pet, second Edition., Howell Book house, Wiley Publishing, Inc., New York, 126pp.
- Wayne Toven, 2000. Old blue eyes: Spawning *Archocentrus spilurum*: In: Tank topics, Greater Akron Aquarium Society.
- Prabu, D.L., S.A. Sudhagar and S. Ferosekhan, Blue eyes: A suitable community tank cichlid, Aquafind.
- Axelrod, and R. Herbert, 1997. Dr. Axelrod's Atlas of freshwater fish, THF Publications, Neptune, New Jersey.

Searching for ecological ways to reduce WSSV impact

Roel Bosma¹, Eleonor Tendencia², Marc Verdegem¹, and Johan Verreth¹.

1: Aquaculture Center, Animal Science Group, Wageningen UR, Netherlands; 2: South-East Asian Fisheries Development Centre (SEAFDEC), Ilo-ilo, Philippines. Correspondance: roel.bosma@xs4all.nl

White spot syndrome virus (WSSV) has brought financial losses to all shrimp farming systems, and lately the “Early Mortality Syndrome” (EMS) or more accurately termed Acute Hepatopancreatic Necrosis Disease (AHPND) have added to the threats to shrimp farming in South Asia. Most studies on WSSV have been done in tanks with species other than *Penaeus monodon*. Several studies of RESCOPAR aimed to study WSSV epidemiology in on-farm situations and find ecological means of disease prevention or control. To achieve these goals experimental, cross-sectional, longitudinal and case studies were carried out by PhDs in Indonesia, the Philippines (Tendencia, 2012) and Vietnam.

Overview of factors increasing or reducing risk

From the literature six categories of risk factors for WSSV are known: the quality and the treatment of the post-larvae (PL), the chemical, physical and biological parameters of the water, and environmental factors such as weather and birds. The question is to what extent the farmer can influence these risk factors through management. Hereafter we summarise the results of studies on polyculture of *Penaeus monodon* with crab or finfish and semi-intensive monoculture.

Low water temperature, low salinity, low transparency and high water level, and fluctuations in temperature, salinity and pH were identified as important risk factors that will result in an infection but not necessarily in an outbreak. Exposure to high salinity and high temperature are important factors for an infection to result in an outbreak of disease. The risk of an infection is reduced when the water temperature is high, salinity fluctuations are small, and percentage of yellow *Vibrio* colonies is greater than the green ones. The contradictory effect of high temperature on WSSV infection and outbreaks might be related to temperature fluctuation. To reduce the weather related risks, using removable rainscreens for the ponds might be a feasible option for intensive farms. However, the effects of water depth and water transparency need further study.

A case study comparing bio-physico-chemical properties of three ponds of a farm having experienced a WSSV outbreak in 2006 but not in 2005, showed that luminous bacterial count (103 cfu/ml) and percentage green vibrios (>50%) were higher in ponds developing white spot disease (WSD). The synergistic effect of temperature fluctuation of 3–4°C within a 10 h period, frequent salinity fluctuation to lower than 15ppt and high presumptive *Vibrio* count (104 cfu/ml) were identified as risk factors conducive to WSD.

In the past, crabs were identified as potential risk factor. This motivated the intensive shrimp farms to place nets around the ponds to prevent crabs from entering. However nets do not prevent worms such as polychaetes entering the

ponds. Polychaetes are carriers of WSSV in shrimp ponds in Indonesia, and worm density plays a role in WSSV infection (Desrina et al, 2013).

Our analysis of a dataset aggregating monoculture and polyculture farms in the Philippines showed that feeding live molluscs was a WSSV risk factor, while feeding with phytoplankton was a protective factor (Tendencia, et al, 2011). In monoculture farms, feeding live molluscs, sharing of water source with other farms, having the same water body receiving discharge and providing intake water, larger pond size and higher stocking density were WSSV risk factors. In polyculture farms, stocking during the cold months, and sludge removal and its deposition on the dikes were risk factors. The sludge may contain amongst other things WSSV infected polychaetes. The dataset of the monoculture farms confirmed that a high mangrove to pond area ratio is a protective factor. The last is related to the preference of the shrimp farms in the Philippines for isolated locations along water-streams without any other animal farming activity. Overall there are more risk than protective factors, and biosecurity measures of the farms were not identified as protective.

In Vietnam, a survey of 200 farms after the EMS outbreak identified pond size and the absence of a settling pond as risk factors. Some of the pond preparation parameters (length, water level) and the control of water quality before stocking were factors reducing risk; buying disease screened fry reduced risk especially in rice-shrimp rotation systems.

Greenwater shrimp production systems

Greenwater culture technique is the modification of the old practice of culturing aquatic organisms in fertilised ponds carrying a phytoplankton bloom. In the Philippines version, shrimp are cultured in water sourced from a brackish or marine pond or reservoir in which fish are grown, mostly tilapia. Grazing by tilapia steers the phytoplankton community towards dominance by the green algae such as *Nannochloropsis* sp. or *Chlorella* sp; hence, the name greenwater.

The greenwater culture system was practiced by shrimp farmers to prevent or control luminous bacterial disease. The most used greenwater system raises shrimp and fish in separate ponds; water used to culture shrimp comes from the pond stocked with finfish. Farmers with limited space can isolated the finfish in a cages or pen inside the shrimp culture pond. During the advent of the whitespot syndrome virus (WSSV), the greenwater system was modified by adding another pond stocked with a carnivorous fish. This was based on the hypothesis that the carnivorous fish will eat WSSV carriers such as crabs or polychaetes (Desrina et al., 2013;

Lo et al., 1996). Some shrimp farmers in the Philippines claimed that the greenwater (GW) technology could diminish disease outbreak frequency due to WSSV.

In ponds using greenwater technology the water quality was better (levels of total suspended solids and nutrients were lower) despite feed utilization efficiency being lower (Tendencia et al., 2013). Furthermore, in greenwater farms the daily weight gain and survival improved despite WSSV infection. Overall, the net income from greenwater farms was better than from non-greenwater farms.

Effect of mangroves

The conservation of mangrove is promoted for several reasons (Primavera et al., 2007). Two of these are related to the aquaculture, and others to the farm and community livelihoods and to global environmental services (Brown, 2013). As for aquaculture, a mangrove area cleans the effluent water from the shrimp farms and may provide a barrier for disease transmission. The latter is increasingly recognised by shrimp

Diagram describing the mechanism behind the greenwater culture system. Solid arrows represent processes that happen in both green and non-greenwater; broken arrows only in greenwater systems.

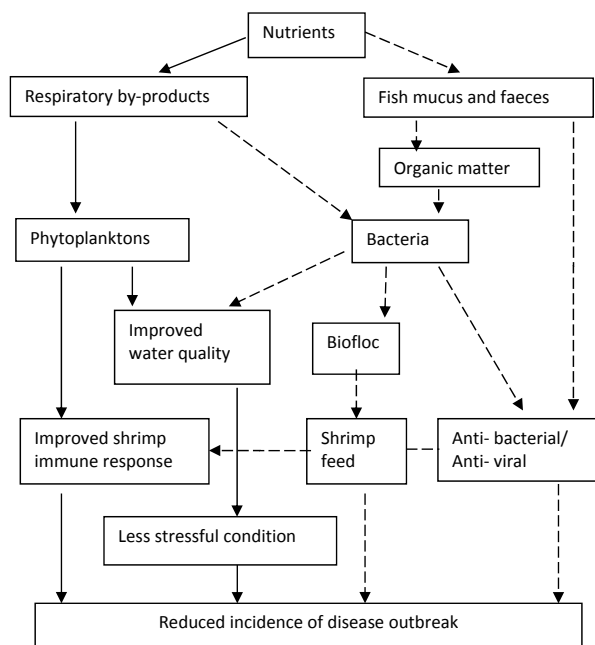


Table 1. The financial results (x1,000 US\$ yr⁻¹ ha⁻¹) of four greenwater and three non-greenwater shrimp farms in 2009 when which shrimp price was low (mean ± SD).

Parameter	Non-GW	GW
Fixed cost *	3.0 ± 1.9	2.8 ± 1.7
Variable costs *	34.9 ± 8.1	34.8 ± 8.9
Value of harvest	41.9 ± 12.2	44.4 ± 9.9
Gross income	6.9 ± 6.6	9.6 ± 7.5
Net income	3.9 ± 6.3	6.8 ± 6.4
* depreciation rate = 10%; Bosma & Tendencia, 2013		



Green water shrimp farms, associated to mangrove forest, on Bohol in the Philippines.

farmers in the Mekong Delta. For a cleansing function the area of mangrove should be 4 to 22 times larger than the shrimp pond areas, which is rarely the case.

While monitoring nine farms with different mangrove to pond area ratios (MPR; 0:1, 1:1, 4:1) WSSV in shrimp was detected on one farm with a MPR of 4:1 and on three farms with a MPR of 1:1 (Tendencia et al., 2012). However, the infection did not result in WSD despite shrimp culture conditions with high levels of organic matter and inorganic nitrogen (NH₃, NH₄, TAN) levels, in combination with low soil pH. The water quality in rearing ponds was independent of MPR. However, soil analysis showed a significantly lower percentage of green vibrios in the sediment when the MPR was 1:1 or 4:1, and a significantly higher level of available sulphur with a MPR of 4:1. The lowest water pH was observed with a MPR of 4:1, observing more black bacterial colonies belonging to the genus *Shewanella*. The latter contribute to nutrient cycling and remediation of contaminated soils, and are a probiotic (Zadeh et al. 2010). Though the physicochemical properties of the water and soil and the mechanisms that would reduce disease transmission have not yet been elucidated, associating shrimp aquaculture to mangrove forestry or locating shrimp farms in mangrove forest is considered advantageous to sustainability.

Mangrove and shrimp culture can also be integrated. These mixed systems are frequent in Vietnam and promoted for organic certification. In such systems shrimp is cultured in the large ditches between stretches of mangrove (see pictures in article of Ha & Bush in this issue). These culture systems are mostly extensive and produce larger, higher priced, shrimp and a range of other aquatic products, next to the timber and other forestry products. The use of some mangrove species was found to be harmful, while several authors found positive effects of *Rhizophora apiculata* leaves on shrimp survival and growth. Scientists in India demonstrated that WSSV-infected *P. monodon* fed with pellets coated with extracts from the leaves of *Cerriops tanggal* got rid of all WSSV virions, and, pure leaf extracts of *C. tanggal*, *Rhizophora mucronata* and *Sonneratia* sp. were found to exert anti-WSSV activity. Whether or not the mangrove leaves are harmful may also depend on the water exchange rate. In Vietnam, the exchange rate may be too low either due to the system design or due to the regulations imposed on these systems.

Most Vietnamese mixed mangrove-shrimp systems have one sluice-gate only and in some cases dredging the ditches is not allowed.

Discussion and conclusion

The ecology of shrimp culture in ponds, whether or not associated or integrated to mangrove, is complex. Shrimp farming remains a high risk activity. For this reason, many of the larger intensive farms in the Philippines go for only one cropping season of black tiger shrimp.

In the Philippines, farmers with several ponds successfully use the greenwater system as a tool to manage water quality and to reduce losses due to disease. Research might increase the protective effects of the greenwater technology by studying the ways to manage the phytoplankton and the yellow vibrios, and by determining which elements of the tilapia mucus and faeces specifically contribute to the effect.

References

- Brown B. and Fadillah R. 2013. Fish Farmer Field School: Towards healthier milkfish / shrimp polyculture and fish farmer empowerment in South Sulawesi. *Aquaculture Asia* 18(2): 12-19
- Desrina, Verreth J.A.J., Prayitno S.B., Rombout J.H.W.M., Vlak J.M., Verdegem M.C.J. Replication of white spot syndrome virus (WSSV) in the polychaete *Dendronereis* spp. *Journal of Invertebrate Pathology*. In press.
- Tendencia E.A., 2012. 'The relation between farming practices, ecosystems and WSSV disease outbreaks in *Penaeus monodon* farms in the Philippines'. PhD Thesis Wageningen University.
- Tendencia E.A., Bosma R.H., Primavera J.H., Verreth J.A.J., 2012. Effect of different mangrove-to-pond area ratios on influent water quality and WSSV occurrence in *Penaeus monodon* semi-intensive farms using the greenwater culture technique. *Aquaculture* 362–363: 72–79
- Tendencia E.A., Bosma R.H., Verdegem M.C.J. and Verreth J.A.J., 2013. Effect of greenwater technology on water quality and occurrence of white spot syndrome virus (WSSV) in pond cultured *Penaeus monodon*. *Aquaculture Research*, DOI: 10.1111/are.12152 online: 4 MAR 2013.

Fisheries and aquaculture-based livelihoods prospects in East Kalimantan, Indonesia

Bambang Indratno Gunawan¹, Rini Kusumawati², Leontine E. Visser² & Roel H. Bosma³

1. Faculty of Fisheries and Marine Science, Mulawarman University, Samarinda, East Kalimantan, Indonesia; 2. Department of Social Sciences, Wageningen University; 3. Department of Animal Sciences, Wageningen University, The Netherlands.
Correspondence: roel.bosma@wur.nl

Berau is the name of a river, a delta, and a district in the province of East Kalimantan on the island of Indonesian Borneo or Kalimantan. After the declining shrimp yields in the two neighbouring deltas of Tarakan and Mahakam, shrimp aquaculture expanded in the Berau Delta. Yet, as part of the Coral Triangle Initiative, in 2005 the coastal waters including Derawan Islands have been declared a marine park or marine conservation area (MCA). The differences in objectives and perspectives of local government agencies, international conservationist NGOs, and fishers and pond farmers provided an opportunity to study the dynamics of people's livelihoods and marine resources governance, and to provide policy

advice to the district government on the management of coastal resources providing livelihood opportunities to the local people (Gunawan 2012, Kusumawati and Visser, 2014).

Historically, the indigenous Dayak people of eastern Kalimantan did not live on the coast. Buginese fishers from southern Sulawesi (Celebes) have migrated to and settled in these coastal areas from the 19th century onwards, and many are still coming in today search of a better livelihood. In the 1980s the Indonesian government's transmigration program moved people from Java and Bali to settle in the lowland areas of East Kalimantan. Consequently, two-thirds of Berau's present population immigrated after 1995. Access to fish and shrimp ponds are often facilitated by patrons or bosses (punggawa) who are land owning shrimp traders or entrepreneurs with strong financial capabilities and political networks. Their patronage networks extend well beyond Berau to Tarakan and Sulawesi. Successful shrimp farmers or traders can develop their own political-economic network and become a punggawa. The economic, social, political, and religious relationships between a patron and the pond farmers are a fundamental condition to practice extensive pond (tambak) aquaculture in Berau, like elsewhere in East Kalimantan. The patrons provide land, assist in creating the pond and provide the first capital; in return, all harvest passes through their local and global trade network (Gunawan and Visser, 2012; Kusumawati et al., 2013).



A local patron or punggawa.

The Berau Marine Conservation Area

Shrimp fisheries and aquaculture are conditioned by the establishment of the Berau marine conservation area (MCA) by the district government, with support from The Nature Conservancy (TNC) and the World Wild Fund for Nature (WWF). The relevant government regulations are unclear, as the first four nautical miles of the coastal waters are governed by the District of Berau, covering most of the MCA. However, the zoning plan for the marine park based on environmental criteria bears no reference to the district government authority over four nautical miles, and partly overlaps with Berau fishing grounds. Non-local or outsider fishers (andon) take advantage of the confusing regulations by fishing in Berau waters.

To address over-exploitation the provincial government established a surveillance institution (Pokmaswas) in a total of 39 coastal villages, comprised mostly of local elites. However, some of these appear to have been more interested in supporting the decentralised government in their need to raise district revenues than in marine conservation, allowing small-scale outsider fishers to access the coastal waters on the condition of paying for a fortnightly fishing permit, obtained from the District Fisheries Office. This practice has complicated the management of the outsider fishers entering the Berau waters, contributing towards an ambiguous attitude to monitoring them, at the expense of local fishers. The Pokmaswas system has challenged the interests and trust of fellow villagers, including by excluding local mini-trawlers from the coastal waters, while at the same time attracting outsiders, making the boundaries of the marine conservation area highly permeable (Gunawan and Visser, 2012). Ever since its establishment in 2005 this has impeded the development of the Berau MCA.

The dynamics of coastal fisheries

Diversification of fishing gear is an important livelihood strategy for the small-scale fishers of Kasai and Teluk Semanting villages in the Berau Delta. Based on their practical knowledge they take a variety of fishing gear on a single trip, and they also change their use of fishing gear over a life time. Villages seem to specialise in fisheries or aquaculture. The majority (63%) of the fishers in Kasai are trammel netters, 17% fish with mini-trawlers, and only 6% are gill netters. A survey carried out in 2009 showed that 80% of the mini-trawler fishers had a complementary livelihood activity, while among others this varied from 40 to 60 %.

Although there are marked differences between consecutive years, 73% of the fishers in Kasai have experienced a decline in income from fisheries. Still, 70% believe that fishing is their future because they lack the social and financial capital (patrons, credit) to invest in the conversion of the mangrove/nipa forest into ponds, and there is too little land available for pond development. The remaining 30% intends to shift into aquaculture. Data from 2010 (Gunawan, 2012) show that 50% of present-day pond farmers started out as fishers when they migrated into the Berau Delta.

Fishers organise their livelihoods using their knowledge of tidal and seasonal variations, making use of the lunar calendar to plan their fishing trips. Within one month trammel netters effectively fish for 20 days. In the good fishing season with northerly winds (October-March) trammel-net fishers



The fisheries officer (above) is checking an outsiders or "andon" fishers (seen below) fishing permit in the coastal Berau.

could make a net income of 50 US\$ a day, while household expenses were close to 130 US\$ per month. In their decision making the trammel netters in particular have to consider their dependency on patronage networks. The patrons provide them with the capital for investments in the boats and gear, and in return control the harvest. This is a first lead to the conclusion that patronage networks shape decision making, access to marine space and market access, and that these *punggawa* are a cornerstone of development in East Kalimantan in both fishery and pond based livelihoods (Gunawan 2012; Kusumawati 2014).

Pond based livelihoods

Shrimp aquaculture started in the Berau Delta in 1984 by establishing ponds in the areas originally covered by nipa palms (*Nypa fruticans*). The root system of the nipa palms enables easier excavation compared to mangrove trees. In 2010 ponds covered 2,000 ha. In the villages of Pegat Batumbuk and Teluk Semanting aquaculture is the main livelihood source, shrimp being produced both in polyculture (85%) and monoculture (13%) in ponds 200 metres wide by 500 metres long. Farmers spread risks and income from harvesting tiger shrimp (*Penaeus monodon*) and milk fish (*Chanos chanos*), with an additional income from harvesting speckled shrimp (*P. monoceros*) whose larvae enter through the sluice gate. They recognise white spot virus as well as environmental problems that may kill the shrimp.

The larger the ponds, the smaller the deep-enough-area for good aquaculture because mostly the machines excavate just enough soil to make the dikes. Consequently stocking density is low and production extremely low: tiger shrimp 11 kg/ha, speckled shrimp 3.5 kg/ha and milk fish 70 kg/ha (average for 45 farmers). In 2009 and 2010, the gross revenue of these farmers varied from only 1.20 US\$ to 900 US\$ ha⁻¹; the average was about 185 US\$ ha⁻¹. The low shrimp harvest can be explained by the small effective area and by the ponds being opened in nipa palm areas. Nipa palms are mostly found on peat soils which acidify quickly after the regular tidal streams disappear. Consequently, during the first seasons the



water is inappropriate for shrimps that are very sensitive to environmental stress. Still, 75% of all pond farmers, particularly those already owning the land, believe in aquaculture as a future livelihood.

Caretakers of a pond and their patrons/pond owners are mutually dependent upon each other. Most caretakers are heavily indebted to their patron and depend on loans provided by them, but the patron also depends on the farmers for the quality and the quantity of the produce to trade. There are two different contractual arrangements implemented between owners and caretakers: a 50:50 and a 20:80 share-cropping arrangement, depending on the secondary conditions that are included in the contract.

The land issue

Extensive aquaculture is not only about shrimp production: pond opening is a strategy to claim land. The coastal lands of Berau are considered an open access area for immigrants. Village heads may 'sell' land not claimed yet to Buginese patrons, who then engage relatives, often from their home area in Sulawesi as caretakers. Also smaller land-owners interested in aquaculture depend on these patrons for the machines to excavate their pond, and for market access. Thus land in the Berau is a political-economic resource in an arena of private actors and governmental staff. Pond development in mangrove/nypa forest in the Berau Delta, like in the Mahakam Delta before, has become the object of land grabbing practices involving patrons in their roles as pond owner, boss and shrimp trader, local land-owners and village elites, as well as by government officials.

Kalimantan's shrimp value chain

Berau's shrimp culture is linked to the global shrimp value chain through Tarakan, a coastal town 160 km north of Berau. Where Samarinda and Balikpapan play this role for the southern deltas, Tarakan is the centre for internally linked processing companies and shrimp exporters in East Kalimantan. The good quality of the coastal waters in this province gives the shrimp produced here a good reputation

among Japanese importers, and makes it an interesting area for environmental NGOs such as WWF to experiment with standards, and certification through regulatory networks (Kusumawati et al., 2013). The province's shrimp value chain is comprised of a range of regulatory networks, ranging from local artisanal regulatory networks to national and global environmental regulatory networks. Key actors in the artisanal regulatory networks are the patrons or *punggawa* and the entire value chain is defined by their multiple interdependencies in the process of commodity and information transfer. However, their importance is often poorly understood and their power underestimated.

As a response to global concerns about food safety and environment sustainability, both of the national and global environmental regulatory networks introduced an on-farm certification and standardization to regulate pre-production, production and post-production of certified shrimps. In 2010 the Ministry of Marine Affairs and Fisheries (MMAF) introduced GAP standards in an attempt to prevent the spread of white spot disease in Tarakan. Also, in 2008 WWF-Indonesia together with the local cold storage and the environmental agency introduced better management practices (BMPs) based on NACA's 2006 international principles for sustainable shrimp farming. Unfortunately both the government and WWF have chosen not to engage with *punggawa* who are in control of shrimp production and trade networks. Their exclusion from the processes of standardization and certification, and the failure to recognise the social structure of ownership appears a threat to the effectiveness of the implementation of certification as a means of environmental governance (Kusumawati et al., 2013).

Conclusions

In 2005 the coastal waters of Berau district were established as marine conservation area (MCA). Until 2010 the income from fisheries was decreasing due to higher operational costs for fuel and ice and lower catches, a trend that is worsened by environmental regulations reducing fishing grounds. Over-exploitation is aggravated by the decentralised government allowing small-scale fishers from outside the district into the marine park, to increase tax income. Village-level surveillance organisations (Pokmaswas) established by the provincial government appeared to be ineffective because of the power interests of their members. The importance of patrons (*punggawa*) in controlling coastal shrimp fisheries and trade is underestimated.

Pond farming started in Berau in 1984. Three-quarters of the fishers in the Berau Delta see aquaculture as a better livelihood opportunity. Mostly polyculture of shrimp and milk fish is practiced in extensive ponds. It provides good income for some years only, as most ponds are opened in peat soils on excavated nypa palm forests.

In the northern delta near Tarakan, WWF together with the local cold storage and government agencies started experimenting with the establishment of a regulatory network for the production of certified shrimp for the global market. Here too, neither the local government, nor the firm and the international environmental organisation chose to include powerful patrons (*punggawa*) into the regulatory network for the standardisation and certification of the shrimp trade.

Thus, both fisheries and aquaculture provide little perspectives to a sustainable livelihood in the Berau Delta. The two PhD research projects by Gunawan and Kusumawati clearly indicate that local power holders need to be considered in any stakeholders consultation, like patrons (punggawa) who provide financial capital (credit) and social capital (trade network) to a majority of the fishers and pond farmers in East Kalimantan. In the past and in the future, they hold the key to achieving sustainable fisheries and pond management.

References

Gunawan, B I., 2012. Shrimp farming and fisheries: Making a living in the coastal frontier of Berau. Wageningen UR PhD thesis.

Gunawan, B.I. and L.E. Visser, 2012. Permeable boundaries: Outsiders and access to fishing grounds in the Berau Marine Protected Area. *Anthropological Forum* 22(2) 187-207.

Kusumawati, R. 2014. Networks and knowledge at the interface. Governing the coast of East Kalimantan, Indonesia. Wageningen UR PhD thesis.

Kusumawati, R., S. R. Bush and L. E. Visser (2013): Can Patrons Be Bypassed? Frictions between Local and Global Regulatory Networks over Shrimp Aquaculture in East Kalimantan. *Society & Natural Resources* Vol. 26: 898-911.

Kusumawati, R. and L.E. Visser, 2014. Collaboration or Contention? Decentralised Marine Governance in Berau. *Anthropological Forum* Vol. 24 (1) 21-46.

Linking farms and landscapes in the governance of sustainable Vietnamese shrimp aquaculture

Tran Thi Thu Ha, Simon R. Bush, and Han van Dijk

The export-led growth of the shrimp industry over the last decade has created economic opportunities for coastal farming communities, but has also increased the ecological and social vulnerability of coastal landscapes and communities (Käkönen, 2008). The relatively unplanned nature of the expansion of the shrimp industry along the coast (Binh et al., 1997), coupled with the open nature of production systems to the surrounding environment (Bush et al., 2010) and poor monitoring of disease, has made shrimp farming a risky business.

At the same time, a global movement to improve the production of shrimp farming (and indeed aquaculture in general) has emerged. Both governments and NGOs have developed a range of standards that set, in similar

but still different ways, minimum requirements for improving production practices and determine access to export markets. Implementation also involves arrangements to ensure that farmers are able to comply with these standards. However, it is the farmers that determine whether they will comply with these standards, given that for the most part they remain voluntary.

But while voluntary standards are focused on the farm level, where production decisions are made, the ecological and social vulnerabilities experienced by the industry are dependent also on higher scale phenomena (i.e. landscape and coastal). Flows of water and disease vectors create connections between spatially dispersed ponds, as are the impacts from degraded mangrove

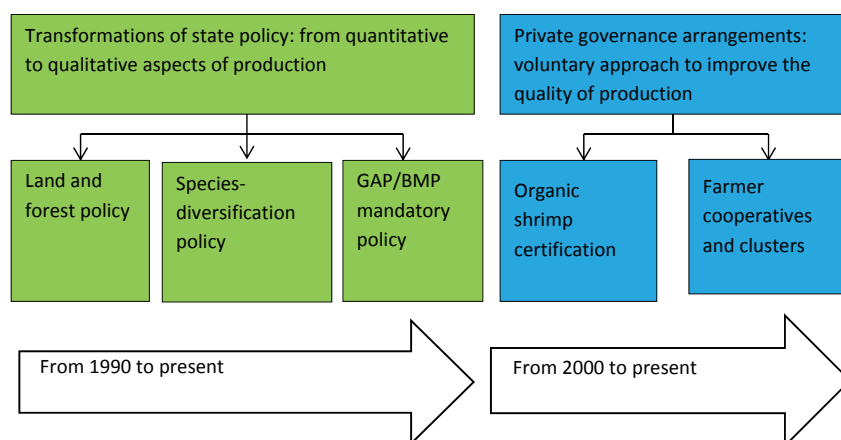
forests. Many of these issues are beyond the remit of public and private standards currently defined at the farm-level. Instead they remain under the control and guidance of the state. Aligning the governance of these two scales – farms and landscapes – is therefore ‘step zero’ in reducing social and ecological vulnerability and improving the resilience of shrimp aquaculture on the long run.

Transformations in governance

The governance of shrimp aquaculture in Ca Mau province has gone through two key transformations over the past two decades: an internal policy shift from quantitative to qualitative state-led production goals, and an external shift to global market consumer’s concerns about the environmental and social impacts of shrimp farming (see Ha and Bush, 2010).

The first transformation, beginning in the 1990s, led to the internalization of external directives for sustainable management of natural resources by the Vietnamese government (Figure 1). This involved a reorientation of land-use and biodiversity policies to meet international agreements. The second transformation, beginning in 2000, was led by the emergence of standards and the government’s wider ambitions for an export-led economy. Standards include the NACA/FAO-led

Figure 1. Transformations of the shrimp aquaculture policy in Ca Mau province, Mekong Delta.



voluntary Better Management Practices (BMPs), national government standard, and private standards such as Global G.A.P., Naturland organic and the Aquaculture Stewardship Council (ASC). These have been supplemented with on-going external attempts to revive organizational forms, such as producer cooperatives (Ha et al., 2013), as a means to enable producers to better comply with these standards.

As external interests through markets and networks become more prevalent in Vietnam, the government finds itself as having to balance global consumer concerns with sovereign control over the shrimp industry by partnering with private companies and NGOs in sustainability agreements. This has in turn meant that the Vietnamese government is positioning itself as a mediator rather than competitor of global private governance arrangements. This is especially relevant as shrimp farmers and related actors are increasingly subject to international forms of regulation, such as hygienic and environmental standards, that extend beyond the immediate control of the state. In this new role, the state can focus on the development of equitable modes of participation in and compliance with these transnational regulatory networks (Table 1).

Organic shrimp certification

Naturland Organic certification of the shrimp-mangrove integrated system in Ca Mau province is illustrative of the changing role of the Vietnamese government (see Ha et al., 2012a). Shrimp produced in these systems is now branded as 'Selva Shrimp' by one of the 'independent' certifiers. A major criteria of the organic standard, in addition to maintaining low extensive farming inputs, is that shrimp farms need to establish at least 50% mangrove forest coverage, use organically certified feed and not use chemicals. Because this was directly supportive of the government goals of mangrove reforestation and conservation in Ca Mau, the government provided support for developing an 'organic coast'; i.e. having mainly organic shrimp farming along its southern coastline by 2015. Next to government several stakeholders are involved in the organic shrimp network: farmers, the forest companies, the shrimp processing companies, various certification and standard organisations and retailers.

In order to realize this environmental goal, three challenges of extending organic certification need to be overcome. First, the government is best positioned to negotiate a realignment of 'organic' expectations regarding the minimum percentage of mangrove forest in relation to existing legislation. Second, improved contractual conditions are needed to ensure that farmers re-capture the two-thirds of the 20% price premium currently absorbed by the downstream actors in the value chain (middleman, processors, exporters and retailers). Third, given the poor credibility of the private sector-led auditing systems currently in place, traceability in the organic shrimp chain is undermined. These challenges indicate that shrimp farmers, the primary producers, are the most powerless actor along the chain, and that collectors and 'middlemen' linking small producers with processors, are perceived to be the 'weakest link' in the chain.

The case clearly indicates that market and state forms of governance over natural resources in Vietnam are closely related. The flow of information between Vietnam, companies and NGOs means that the definition and ultimately imple-

mentation of regulation over shrimp aquaculture is reliant on partnerships between these actors. But what does this mean for farmers? In the case of Naturland certification, it shows an important bargaining and facilitation role for the Vietnamese government. First, smaller farmers can be supported to form a spatial unit of management to collectively reach the 50% minimum forest cover. The management unit could then negotiate for an alternative mode of 'area based certification', away from the farm level and linking smaller scale farm management (and incentives for sustainable practices) with sustainable landscape level management.

Shrimp farmer clusters

Outside the specific conditions of organic shrimp, farmer clusters have been promoted by various international organisations to improve the collective capacity of small-holders to meet sustainability criteria for accessing international markets. Successful cases exist in other Asian countries (e.g. Umesh et al., 2010; Padiyar et al., 2012). But whether and how clustering can be successful in Vietnam remains unclear; especially given the country's history of (failed) agricultural collectivization.

Those promoting farmer clusters argue that they improve the capacity of farmers to: implement disease control measures by linking farm-level management to water management; provide a platform for shared technical learning; create economies of scale for upgrading infrastructure and for access to credit; and allow for improved bargaining power when selling their shrimp (Padiyar et al., 2012). However, while results from Vietnam confirm some of these benefits, they also show that farming clusters may better suit intensive rather than extensive farming systems. Intensive farms already have a degree of shared infrastructure in place, they are more sensitive to the impacts of disease and they see immediate economic benefits associated with purchasing shared inputs such as feed (Ha et al., 2013). In contrast, extensive systems need less input, are more resilient to disease and have minimal shared infrastructure, and thus benefit less.

But can clustering also improve environmental performance and bargaining power? The answer is a qualified 'yes'. It appears that investment in improved farming techniques by following BMPs in both intensive and extensive systems increased as a result of being involved in farming clusters. However, focusing on technical improvements, as is done by the government and NGOs alike, does not necessarily improve economic efficiency or the market access of producers. The prospects for intensive producers to bargain improved contracts with processing companies are overall positive given their volume of production. The on-going economic and regulatory pressure on extensive producers means that clustering is potentially a promising mode of collective bargaining.

Technical improvement through clustering remains important. However, external support to farmers, including that of the government, should consider how farmers can get legal support to improve the conditions of their selling contracts in addition to technical on farm assistance. If wider ambitions to implement market-recognized certification schemes are to be realized beyond the BMPs (Tran et al., 2013), then fairer contract arrangements are central to their future success.

Shrimp farmers and mangroves

Achieving any sustainability outcome in shrimp aquaculture is dependent on the practices and therefore decisions of farmers. In short, little can be accomplished if farmers are not willing to engage with regulation; even in strong states such as in Vietnam. So what are the perceptions on the sustainability of their practices have given the contribution of mangrove forest to their livelihood relative to shrimp farming?

Our answer runs partially contrary to the wider expectation that farmers only maximize their output from shrimp farming at the expense of mangroves. Farmers operating in the Ca Mau shrimp-mangrove system are positive about the maintenance of mangroves on their farms, willing to both plant and protect the trees for economic and environmental benefits (Ha et al., 2012b). However, in order to make such an investment they want to have a greater degree of control over the use of mangroves that by law remain under the control of the government. In more concrete terms, their concerns relate directly to what they see as the unfair distribution of benefits from the timber extracted from their farms that is currently controlled by the state-led forest management boards and forestry companies.

The perception of shrimp farming as the main cause of deforestation and degradation should be reevaluated in the context of the integrated shrimp mangrove model because farmers' income is improved if mangroves are a part of the production system. The evidence gives a strong indication that shrimp farmers are potentially the best stakeholders to plant, protect and manage mangroves if they have full rights and responsibilities over forest. Attention might also be given to alternative payment streams to farmers from, for instance, reduced emissions from deforestation and forest degradation (REDD) compensation payments, which are currently under

debate in Vietnam (Pham et al., 2012). Such choices are on the most part still to be made. The first step is opening the possibility of shrimp farming as a livelihood activity that can promote the planting and protection of mangroves in vulnerable coastal areas.

Conclusions

Reducing the vulnerability of farmers, and indeed an entire industry, requires flexible but robust governance arrangements that can respond to environmental, social and economic change. The current focus of governance arrangements on the farm-level technical risks that farmers face, is unlikely to reduce the vulnerability of farmers. Instead, greater attention should be given to forest conservation and management, as a means of linking farm-level management to coastal landscape management.

This is especially relevant given the open or integrated character of most shrimp farms in the Mekong Delta. The central role of Vietnamese government remains vital at the landscape level – more so it appears than at the farm-level. The trend towards market-based approaches focused on the farm-level, and which the Vietnamese government response may then be complementary. Decisions will remain on the farm-level, as well as the definition of technical standards and certification. Both state and private governance arrangements therefore have to be explicit about the scale at which they operate and also the ways in which they complement.

Certification and farmer clusters have the potential to improve the wider environmental status of coastal areas. But to do so they need to link the regulation of farm level practices to landscape level ecological processes that, for example, affect the spread of disease. Three challenges need to be

Table 1. Challenges of governance arrangements and (potential) roles of the state.

Main challenges of governance	Suggested roles of the state
1. Organic shrimp certification	
<ul style="list-style-type: none"> Involvement of farmers as partners rather than targets of regulations. Unfair premium-sharing mechanism for certified farmers. The legitimacy and credibility of private auditing systems. 	<ul style="list-style-type: none"> Converge the national standards with international (organic) standards. Facilitate negotiations between farmers and processing companies and other actors. Monitor the quality of private auditing systems.
2. Shrimp-farmer clusters	
<ul style="list-style-type: none"> Externally induced creation of shrimp-farmer clusters without regard for farmers' needs and abilities. Ability to establish contracts between clusters and actors along the value chain (vertical integration). Ability to generate economic benefits from cluster formation. Ability to ensure the long-term operation of farmer clusters. 	<ul style="list-style-type: none"> Provide initiatives to cluster with support and infrastructure for development. Create a legal framework to help private actors to play their roles in extension and credit services. Better enforcement of legislation with respect to contracts along the value chain. Support the incorporation of BMP/GAqP in contract farming. Provide management know-how to clusters.
3. State mangrove forest policy and management	
<ul style="list-style-type: none"> Perception that forest allocation to households will lead to mangrove clearance for shrimp farming. Unfair implementation of the forest benefit sharing policy by state forestry companies and forest management boards. 	<ul style="list-style-type: none"> Consider integrated and associated shrimp-mangrove systems as a good practice for the management of mangroves forest. Become controller instead of manager of the mangrove forest. Apply an inter-sectoral approach to support the shrimp farms at local level.

addressed to ensure that farm level decisions driven by private governance arrangements will create benefits across coastal landscapes:

First, the perception in both government and NGO circles that shrimp farmers are unable and unwilling to maintain and even expand mangroves should be revisited. If incentives are clear and well designed, farmers may prove to be the most effective managers of mangroves.

Second, the inequitable distribution of benefits between farmers and other industry actors needs to be addressed by more independent legal institutions; contracts need to be clear and enforceable, and those in breach need to be made accountable.

Finally, while accepting that consumer or retailer led standards embrace more trust, the government needs to be prepared to play a more central role in the definition and operation of private or market-oriented arrangements to ensure equitable and effective participation of a wide range of industry players.

References

- Binh, C., M. Phillips & H. Demaine (1997). Integrated shrimp-mangrove farming systems in the Mekong delta of Vietnam. *Aquaculture Research* 28(8): 599-610.
- Bush, S.R., P.A.M. Van Zwieten, L. Visser, H. Van Dijk, R. Bosma, W.F. De Boer & M. Verdegem (2010). Scenarios for resilient shrimp aquaculture in tropical coastal areas. *Ecology and Society* 15(2): 15. [online] URL: <http://www.ecologyandsociety.org/vol15/iss2/art15/>.
- Ha, T.T.T. & S.R. Bush (2010). Transformations of Vietnamese Shrimp Aquaculture Policy: Empirical Evidence From Ca Mau Province, The Mekong Delta. *Environment and Planning C: Government and Policy* 28(6): 1101-1119.
- Ha, T.T.T., S.R. Bush, A.P.J. Mol & H. Van Dijk (2012a). Organic coasts? Regulatory challenges of certifying integrated shrimp-mangrove production systems in Vietnam. *The Journal of Rural Studies* 28: 631-639.
- Ha, T.T.T., S.R. Bush & H. van Dijk (2013). The cluster panacea?: Questioning the role of cooperative shrimp aquaculture in Vietnam. *Aquaculture* 388-391(0): 89-98.
- Ha, T.T.T., H. van Dijk & S.R. Bush (2012b). Mangrove conservation or shrimp farmer's livelihood? The devolution of forest management and benefit sharing in the Mekong Delta, Vietnam. *Ocean & Coastal Management* 69: 185-193.
- Käkönen, M. (2008). Mekong Delta at the crossroads: more control or adaptation? *AMBIO: A Journal of the Human Environment* 37(3): 205-212.
- Padiyar, P.A., M.J. Phillips, B. Ravikumar, S. Wahju, T. Muhammad, D.J. Currie, K. Coco & R.P. Subasinghe (2012). Improving aquaculture in post-tsunami Aceh, Indonesia: experiences and lessons in better management and farmer organizations. *Aquaculture Research* 43(12): 1787-1803.
- Pham, T., M. Moeliono, T. Nguyen, H. Nguyen & T. Vu (2012). The context of REDD+ in Vietnam: drivers, agents and institutions. *CIFOR Occasional Paper* 75.
- Tran, N., C. Bailey, N. Wilson & M. Phillips (2013). Governance of Global Value Chains in Response to Food Safety and Certification Standards: The Case of Shrimp from Vietnam. *World Development* 45(0): 325-336.
- Umesh, N.R., A.B.C. Mohan, G. Ravibabu, P.A. Padiyar, M.J. Phillips, C.V. Mohan & B.V. Bhat (2010). Shrimp Farmers in India: Empowering Small-Scale Farmers through a Cluster-Based Approach. *Success Stories in Asian Aquaculture*: 41-66.

Resilience of shrimp farming based livelihoods in the Mekong Delta, Vietnam

Tran Thu Phung Ha, Han van Dijk, Leontine Visser, Roel Bosma

In Mekong Delta's southern provinces, Bac Lieu and Ca Mau, the rural livelihoods are mainly based on fisheries and shrimp farming. The main shrimp farming systems are intensive and improved extensive, of which the last may be integrated or associated with mangrove. Integrated means that most ponds are canals amidst stretches of mangrove, while in associated shrimp-mangrove systems the mangrove forest is a large plot clearly separated from the pond areas.

Decision-making in shrimp farming considers several risks and uncertainties. Next to the disease risks and ecological uncertainties farmers are subject to economic uncertainties (market prices of inputs and shrimp), social, political and institutional processes. Though all are pursuing increased incomes, this multitude of factors means that the livelihood history of households of shrimp farmers and fishers may follow different pathways. In 2009, about approximately 70% of the households reported that shrimp farming today was riskier than five years ago. Farmers cited environmental problems associated with shrimp disease as their main cause of failure. To them, shrimp diseases are caused by deforestation, soil degradation, and pollution from sewage water and sediments in the canals, by salinization, and the

use of unqualified shrimp seed. The water is polluted because the canals act as both clean water supply and wastewater sinks. Consequently, disease agents in the effluents from one farm are transmitted to neighbouring farms. This problem is observed both in aquaculture systems with and without mangroves, in both extensive and intensive farming. Households in the mangrove-shrimp integrated system appreciated the water infrastructure more than households in the non-mangrove system (Table 1).

Water quality in the intensive non-cluster systems scored worse. These systems dominated in areas where mangroves were totally destroyed after 1975; the water infrastructure consisted of narrow canals causing downstream wastewater pollution, water shortages in the dry season, and thus increased risk of transmission of shrimp disease. Farm density here is high also, thus reducing the capacity of the environment to function as bio-filter for the wastewater from the ponds.

Shrimp diseases occur during the whole year but systems experience the highest risk in different periods of weather change. The extensive system with mangrove suffers mostly

when the dry and rainy seasons are shifting. According to farmers, the rains have become more unpredictably in recent years, which has made shrimp farming more vulnerable to failure.

Farmers strategies to prevent diseases

Once disease manifests itself farmers saw no way to stop the disease from spreading by better pond management, except by using medicines. However, farmers in the different farming systems developed different social and ecological pathways to reduce the risk on disease outbreaks.

The improved extensive system is characterized by continuous harvest of large sized shrimp, and restocking. Besides *P. monodon* farmers stock crabs, fish (sea-perch, anabas), blood cockles. The farmers exchanged water during the low and high tides of every spring tide. They would decide on how long and what day they open or close the sluice gates according to their experiences with the water colour in their ponds and in the canals. In addition they decided to stock low price fry from local hatcheries at low density. The purchase was normally based on the price of fry, their confidence in the hatchery branch, their relationship with traders and advice from others. They also diversified by recruiting or stocking mud crab, fish (sea-perch, anabas), and blood cockles to generate income and to mitigate the risk of shrimp production failure. Moreover, to reduce the risk of shrimp mortality due to the polluted inlet water, some applied new technologies such as minimal water exchange with filter pond.

In the intensive system, farmers clean and dry the pond completely after a harvest, remove the debris and try to control the water pH and salinity. Selection of good quality fry for stocking was important. Farmers preferred to get healthy fry and purchased them from reliable hatcheries that tested for major pathogens. All this did, however, not secure success as more than 20% of the interviewed intensive shrimp farms had dealt with diseases. Disease from virus infections such as white spot disease virus (WSSV) killed all shrimp quickly in a very early stage. Yellow head disease virus (YHD), monodon baculo virus (MBV) and many others from microbes, fungi and parasites occurred during a crop. Farmer's best strategies were to empty the ponds, sometimes for several seasons, and/or change to fish or mud skipper farming. However, unsuccessful farmers found it difficult to access financial credit to continue/restart shrimp farming if they could not repay earlier debts.

Higher financial uncertainty of intensive shrimp farming

In 2008, the shrimp price sharply dropped by one third, while input costs increased by 20-40%. For example, the price of 25g shrimp decreased from VND 105,000 to 65,000 in six months. For larger shrimp (21-30 shrimp kg-1) the decrease was much less: VND 109,670 to 106,110. This decline was caused by the global economic crisis, by unstable markets, the large number of actors involved in the market chain, such as collectors, retailers, and processing traders, and to global overproduction.

In the improved extensive farming systems, price decline and fluctuation was not the primary concern because operational costs were low, and the better priced larger size shrimps were harvested all year round. In addition, in the mangrove-shrimp system, in order to increase the market value, some farmers choose to use better management practices (BMP), good aquaculture practices (GAP), or organic shrimp farming approaches. If these systems are correctly applied, farmers can get higher benefits from the shrimp.

Farmers in intensive shrimp systems were heavily exposed to the risk of shrimp market decline, especially since at harvest time, their shrimp must be sold at any price because the harvest cannot be stored. Moreover, the system required higher investments, is thus more vulnerable to fluctuating market prices, hence a higher risk of financial loss. To control the negative effect of shrimp price fluctuation on the market they choose the months of stocking and harvesting they thought were best to obtain higher profits. For example, they guessed that the price of shrimp might increase in the second half of the year because of the export quota were assigned to the processing companies in the middle of the year, or in the weeks of the Lunar New Year holiday due to the bigger consumption of shrimps in the domestic market.

Unexpectedly however, in 2008 the price of shrimp slumped dramatically and many farmers emptied their ponds and found non-farm occupations as small traders or industrial workers instead. The farmers of the Nhi Nguyet cluster decided to minimize operational costs by applying new ways of pond management or by changing production system. They stocked all of their shrimp-seeds in one pond and then divided them over several ponds after the shrimp gained weight, thus reducing cost for feed and chemicals, and saved fuel for the paddlewheels. Others decided to change to *P. vannamei* farming which promised a higher yield and more net income. The first eight farms started growing *P. vannamei* in the middle of 2008, and the number increased to 30 farms in the beginning of 2009, while at the end of 2010 all farms in the cluster had shifted to the *P. vannamei*.

Capability to build resilience at household level

The household's strategies to build resilient livelihoods can be clustered into the three categories, according to the aimed time-frame and social involvement.

The short-term strategies were migration and risk mitigation. Immigration included both temporary and permanent migration for non-farm jobs in industrial cities, within or out of the province or international migration, either for skilled or unskilled labour. Data from the Population and Housing Censuses show that the number of long term emigrants doubled from 1984-1989 to 1994-1999; and from 2000-2005 more than 3,000 workers left the Mekong Delta annually. To mitigate risk, shrimp farmers and fishers diversified their livelihoods by engaging in animal husbandry and crop cultivation, labour exchange for emptying ponds, collecting shrimp and fingerlings and doing off-farm activities such as small-scale trading and providing services, eg. at least half of the households with extensive shrimp systems without mangrove shifted (partly) to less risky livelihood options: salt production and fish farming (eels, mudskipper) requiring

smaller investments. However, price of the salt again sharply was reduced at the end of 2008 due to overproduction and over-importation. The salt market decline strongly effected households' livelihoods; many had half-heartedly produced and stored salt awaiting the price to increase.

To improve long-term benefits households nurture their capacity for learning and adapting. For example, they participate in training to improve their know-how and be able to do more skilful jobs, or they send their children to school. The livelihood activities become more flexible, specialized and professional; e.g. they apply new technologies in farming or protect the mangrove forest. Formal institutions, as extension systems and mass associations foster this process by learning farmers to apply more advanced techniques producing higher quality and safer products, and to protect the environment.

The creation of opportunities for self-organization aims to improve both short-term and long-term benefits. Shrimp farmers preferred to participate in more accessible informal rather than formal networks. Farmers joined informal networks, and collaborated with neighbours and relatives, to solve conflicts and build external networks. These networks provided them to access to credit, know-how, support, and services from traders, patrons, and moneylenders. Through the cluster "Nhi Nguyet" the farmers build relationships with external agencies for support and collective buying of inputs, and with processing companies to enhance access to credit and to avoid fluctuations of the market price. Through the cluster they acquire a stronger legal and equity position.

The private sector networks and state-based agencies differ both in their functioning and in the perception local shrimp farmers and fishers have on them. It is more difficult to access

Table 1. The natural and physical capabilities of four shrimp farming systems (mean \pm SD).

Items	Improved extensive		Intensive		Average
	Non-mangrove	mangrove	Non-cluster	cluster	
Number of households sampled	27	59	29	23	
Total area (ha)	4.3ab \pm 4.5	5.5a \pm 3.1	1.0c \pm 0.7	3.0bc \pm 2.8	3.9 \pm 3.5
Pond area (ha)	3.7a \pm 3.9	1.8b \pm 1.0	0.6b \pm 0.3	1.1b \pm 0.5	1.7 \pm 2.1
Satisfied with water quality (%)*	34	58	0	65	42
Satisfied with infrastructure (%)*	7	27	45	39	29
Having electricity (%)	59	54	83	61	62

Different superscripts (a, b) denote significant differences between means within rows ($p < 0.05$).

(*) denotes a significant difference between the percentages within a row ($p < 0.05$).

Table 2. Household perception of causes of risks in shrimp farming and of the season during which farms are affected by shrimp disease, according to four shrimp production systems (n).

Items	Improved extensive		Intensive		Average
	Non-mangrove (27)	Mangrove (59)	Non-cluster (29)	Cluster (23)	
Causes of increased risk (%)					
Water pollution	67	76	72	56	70
Unexpected weather *	48	61	7	22	41
Low price *	0	3	17	68	16
Lack of technique *	7	8	28	26	15
Small size of land	4	20	14	0	12
Unqualified shrimp seed	7	3	31	0	9
Seasons of shrimp diseases (%)*					
Whole year	41	15	76	65	41
Beginning of rainy season	18	49	10	0	27
During rainy season	18	27	10	4	18
End of rainy season	22	2	3	13	8
Cold weather	0	7	0	9	4

(*) denotes a significant difference between the percentages within a row ($p < 0.05$).

Table 3. operational costs and net income (million VND) from shrimp farming, secondary income, expense and the percentage of households with negative net income (mean \pm SD).

Items	Improved extensive (n=86)		Intensive (n=52)		Average
	Non-mangrove (27)	Mangrove (59)	Non-cluster (29)	Cluster (23)*	
Operational cost per ha	7b \pm 4.2	14b \pm 8.1	254a \pm 165.9	308a \pm 159.3	112 \pm 163.7
Net income aquaculture per ha	6b \pm 8.0	14b \pm 11.9	68ab \pm 179.8	101a \pm 138.6	38 \pm 105
Benefit-cost ratio	0.86	1	0.27	0.33	
Secondary income per HH	9b \pm 15.4	7b \pm 12.9	18ab \pm 17.1	31a \pm 69.2	13 \pm 32
Total income per HH	40b \pm 63.7	31b \pm 26.3	60b \pm 80.4	146a \pm 161	58 \pm 90.7
HH with negative net income (%)*	15	10	24	22	16
HH children become farmers	52	36	7	30	32

Different superscripts (a, b) denote significant differences between means within rows ($p < 0.05$).

* Samples include both *P. monodon* and *P. vannamei* farming.

state services because of cumbersome procedures and in general the greater distance compared to private sector partners. The degree of trust within private sector networks is higher even in case of patron-client relations, and farmers judged the knowledge exchanged in these networks more relevant. Though collaboration with private sector networks help to overcome shocks, it also promotes more intensive farming of shrimp and exploitation of the environment, thus endangering ecological resilience.

The incomes of shrimp farming households

Among the two intensive farming systems, the net income per household in the cluster is more than twice that of non-cluster farmers. The cost-benefit ratio in the cluster system is slightly higher than the non-cluster system (0.33 versus 0.27), and fewer farms are failing (22% versus 24%) due to shrimp diseases. In extensive and mangrove systems counting the losses due to disease is difficult because the system functions on the basis of continuous recruiting and harvesting.

Among the extensive systems, the households in the mangrove-shrimp system experienced lower failure rate compared to those without mangroves (Table 3). However more of the last consider their livelihood sustainable (want children to continue farming) which is due to more options for diversification.

In a mangrove-shrimp system net income from aquaculture was higher as more wild shrimps and fishes were harvested than in systems without mangroves. Among the shrimp-mangrove farms, in particular the households with an integrated mangrove-shrimp system have a higher net income from aquaculture than the ones in an associated/separated system. However, others find the inverse for the long term benefits. Regarding the mangrove forest, after a production cycle of 12-15 years and after deduction of all the costs for plantation, harvest and taxation, all farmers could receive up to VND 5.9 million ha⁻¹ year⁻¹ (USD 310 in 2010). However mostly they got less due to unfair sharing regulations.

Is fishing an alternative livelihood?

Non-successful shrimp farmers might consider fishing as an exit strategy. However, the increased number of fishing boats was, next to the environmental degradation, one reason for the decline in fish stock and catch, according to the fishers. In addition, the increased cost of gasoline, especially in 2008, of fishing gear and of boat maintenance caused a negative balance. Although the annual net income per household (approximately VND 40 million = USD 2,300) was slightly higher than that from extensive aquaculture (VND 34 million), many fishers were not satisfied with their job because of its high risk and uncertainty. Our survey showed that 65% of the parents did not want their children to become fishers and that 54% of the households considered their livelihood to be worse than ten years ago.

Discussion and conclusion

Though from an environmental point of view the cluster of intensive systems is interesting because of its low density of farms scattered over a large area in between mixed forests, the system fails in terms of social resilience at the level of the household. In case of shrimp diseases or market decline the farmers in these intensive systems are most affected. The livelihoods of the farmers involved in this intensive system are not sustainable under conditions of high risk of incomes instability and environmental degradation. Besides, sources of technology supports, qualified shrimp seeds providers, guaranteed contracts for input and output markets and, most importantly, the maintenance of ecological resilience need to be well considered. In other words, the trade-off between economic development for a small rich elite and the decrease of the social resilience for a whole community needs to be seriously addressed.

The Vietnamese Government established a strong institutional system to support rural development including an extension system, mass associations and financial credit systems. However, in particular the farmers involved in the improved extensive system are being neglected in the knowledge transfer from the extension service, while those in the intensive system very much depend on the patron-client relationship due to credit. The dependent farmers often are unwilling to participate in formal institutional organizations and prefer their own informal networks, even if these sometimes include exploitation.

Livelihoods in the Mekong Delta are vulnerable and under social-ecological pressure. Farmers have created pathways to adapt, and to learn to manage the changes in the short-term and the long-term. Clustering, or other forms of cooperation, facilitated the adoption of new technologies such as *P. vannamei*, which was a way to improve both production and income of intensive farming systems. Diversification and migration allow the improved extensive systems to stay in business. The extensive integrated mangrove-shrimp system provides a better livelihood at present, than the associated mangrove-shrimp system. At present, the last has too little prospects for diversification.

The institutional interventions, firstly, need to focus on balancing between household economic improvement and natural resources conservation. Socio-economic improvement through poverty alleviation programs is important particularly for low-income households, since the middle-income households are often the ones that can already 'afford' conservation, whereas the poorest households cannot. Although the policies on integrated shrimp-mangrove management and fishery are meant to increase the social-ecological resilience of the system, they do not necessarily stimulate an increase of the social and economic resilience of the households, which may negatively affect the social-ecological resilience of the system in the end. Thus we recommend to devolve the responsibilities and rights for the management of the mangrove forests and the coastal inshore resources to local individual farmers and communities, to promote farmers collaboration and (organic) shrimp certification systems, and to enhance non-farm or non-fishing livelihood diversification.

Farming system affects the virulence of white spot syndrome virus (WSSV) in penaeid shrimp

Tran Thi Tuyet Hoa, Nguyen Thanh Phuong, Mark P. Zwart, Mart C.M. de Jong and Just M. Vlak

Clinical signs of WSSV infected shrimp

White spot disease (WSD) has been a major scourge of shrimp culture since the 1990's. WSD is caused by the white spot syndrome virus (WSSV). This causative agent has spread around the world through shrimp trade. Treatment of WSD is not presently possible and therefore monitoring and prevention strategies were developed. However, shrimp farmers often fail to apply adequate biosecurity measures or to use WSSV-free post-larvae to mitigate WSD. The use of the white leg shrimp (*Penaeus vannamei*), next to black tiger shrimp (*P. monodon*) provided only a temporary relief. Efforts to control WSD were further challenged by the emergence of new WSSV strains with higher virulence, i.e. increased severity of infections and ability to cause mass mortality in shrimp populations. We studied the power of WSSV to cause disease and mortalities using molecular epidemiological tools. The various strains of WSSV have a different genotype structure, which can be distinguished using so-called PCR-genotyping (see Box 1). The relationship between genotype structure, farming systems and disease outbreak is often anecdotal and lacks statistical support. We used molecular typing methods as input to quantify these relationships to further understand the epidemiology of WSD in pond systems.

WSSV genotyping

Our study used the genome of WSSV-isolate TH (having 292,967 base pairs) as a reference (Van Hulst et al., 2001). The Vietnamese WSSV was characterised by two major deletions found in the open reading frames ORF-14/15 (Indel-I) and ORF-23/24 (Indel-II) and three regions with variable numbers of tandemly repeated sequences (VNTRs) located in ORF-75, ORF-94 and ORF-125 (Dieu et al., 2004). We used both the Indel and VNTR regions for characterising WSSV at the local and regional level and found more variation in



Clinical signs of WSSV.

the VNTR regions than in the Indel regions. We correlated the genotyping outcome with farming systems and disease outbreak status by applying rigorous statistical methods.

We examined the variation among WSSV isolates from *P. monodon* shrimp hatcheries and farms in different regions of the Mekong Delta. Analysis of approximately 157 WSSV isolates showed common variations in the number of repeats, with some broodstock harbouring more than one genotype. WSSV genotypes with a high number repeats (i.e. ORF94-23 and -14), present in infected wild crab and wild shrimp, however, were not detected in cultured shrimp from the same pond. This implied that stocked postlarvae rather than invading wild crustaceans were the source of WSSV infection and WSD in the studied ponds. The findings showed that the VNTR of ORF94 could be used to trace the origin of WSSV infection at shrimp ponds or shrimp farming regions and for tracking and typing WSSV isolates at the farm-scale level.

The link between WSSV genotypes, disease outbreaks and the farming system

We investigated the correlation between the number of RUs including the other VNTR regions (ORF75 and ORF125) on the one hand and WSD outbreak status and shrimp farming practice on the other. A total of 662 WSSV samples from WSSV-infected *P. monodon* were collected from 104 ponds in three shrimp farming systems: semi-intensive, improved-extensive and rice-shrimp systems. Analysis of these WSSV samples revealed 18, 14, and 8 different genotypes, respectively (Table 1). Genotyping data in combination with statistical analysis showed that VNTR sequences of ORF94, ORF125 and ORF75 were useful markers for studying WSSV population structure. In addition, on the basis of specific VNTRs of ORF94 and ORF125, the genotype population structure of WSSV also correlated with disease outbreaks in shrimp ponds. Populations of WSSV with low repeat numbers, i.e. shorter genes, correlated with disease, regardless of the shrimp farming practice (Hoa et al., 2012a).

We also investigated 313 WSSV-infected shrimp collected during 2006 to 2009 from 76 shrimp ponds in the Mekong Delta. We characterised the WSSV genotypes by analysing Indel-I and Indel-II. None of the Indel-I types showed a relation with semi-intensive farming systems and the

Table 1. The number of WSSV genotypes observed in different shrimp farming system.

System	Number of genotypes
Semi-intensive	18
Improved-extensive	14
Rice-shrimp	8

occurrence of disease. But Indel-II detected genotype showed variation in terms of farm geographic location. More importantly, the presence of a specific Indel-II of 10,970 base pairs in length was found to correlate statistically with the occurrence of WSSV-induced disease and the use of semi-intensive farming systems. This suggests that Indel-II can be an informative molecular marker for predicting WSSV-induced disease.

The analysis of Indel and VNTR regions also showed that WSSV mixed-genotype infections correlate with lower outbreak incidence and that, in contrast, disease outbreaks correlate with single-genotype infections (Hoa et al., 2012a, b). Non-outbreak ponds had a significantly higher frequency of mixed-genotype infections than outbreak ponds for all VNTR regions of WSSV, both at the individual shrimp as well as at the pond level.

Using the molecular markers for the three VNTR regions we studied the spread of WSSV within and between farms in two different farming systems: improved-extensive and semi-intensive. Results showed that the transmission of WSSV infection on improved-extensive shrimp farms appeared to be mainly due to the recycling of WSSV over time in the same pond, whereas in semi-intensive shrimp farms transmission of WSSV was mainly from neighbouring ponds.

Conclusion

The variable regions at the otherwise very conserved WSSV genome can be used to address epidemiological questions. We focused on the relationship between genotype structure of WSSV populations on the one hand and disease outcomes and farming system on the other. We provided evidence that a particular WSSV VNTR structure (in particular the number of repeat units in ORF94) statistically correlate with disease outbreaks and to a lesser extent to farming system. In addition mixed-genotype WSSV infections of shrimp are negatively correlated with disease outbreaks in ponds. Finally, it might be possible to use molecular markers (ORF94 and ORF125) to predict the outcome of WSSV infections in shrimp ponds in the future. For shrimp culture, these findings provide important information for the development of specific management strategies to control WSD and to advice farmers as to whether to harvest or not.

References

- Dieu BTM, Marks H, Siebenga J, Goldbach R, Zuidema D, Duong TP, Vlak JM (2004) Molecular epidemiology of white spot syndrome virus within Vietnam. *J Gen Virol* 85: 3607-3618
- Tran Thi Tuyet Hoa, Zwart MP, Phuong NT, Vlak JM, de Jong MCM (2012a) Low numbers of repeat units in VNTR regions of White spot syndrome virus are correlated with disease outbreaks. *Journal of Fish Diseases* 35: 817-826.
- Tran Thi Tuyet Hoa, Zwart MP, Phuong NT, Oanh DTH, de Jong MCM, Vlak JM (2012b) Indel-II region deletion sizes in the white spot syndrome virus genome correlate with shrimp disease outbreaks in southern Vietnam. *Disease of Aquatic Organisms* 99: 153-162.
- van Hulst MCW, Witteveldt J, Peters S, Kloosterboer N, Tarchini R, Fiers M, Sandbrink H, Lankhorst RK, Vlak JM (2001) The white spot syndrome virus DNA genome sequence. *Virology* 286: 7-22

Box 1. Molecular typing of organisms

Each organism, e.g. animals, fishes, plants, bacteria, viruses, has a characteristic genome sequence with genes (representing functions) and intergenic regions. The number of genes is more or less fixed for each species. WSSV has about 290 open reading frames (ORFs = genes) depending on the isolate. Genes are composed of a series of defined base pairs. The number of base pairs (size) varies per gene, but the number of base pairs is huge: several thousands to millions. The sequence of base pairs can be related to genetic characteristics (functions) and is specific for each individual in a population. Variation in base pair sequence can thus be used to 'type' a species or a variant.

Each time an organism reproduces, some base pairs may alter, are just lost (deletions) or added (e.g. by duplication); sometimes genes lose base pairs and become shorter. Although many base pairs seem to have no specific function, losing a set of some base pairs can have consequences and may result in a new strain of a species. The number and the type of base pairs are characteristic for a strains within a species and target for 'typing' by molecular methods.

Figure 1. Schematic overview of the used ORF and VNTR regions at WSSV

