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Sustainable intensification of aquaculture in the Asia-Pacific region

Documentation of successful practices

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REGIONAL OFFICE FOR ASIA AND THE PACIFIC
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Foreword

Asian aquaculture has achieved outstanding growth in the past three decades with an average annual rate of nearly 10 percent. As a result, Asia is now contributing about 90 percent of the global aquaculture production. Fish now supply over 20 percent of animal protein in the diet of the Asian population and 60 percent of this is from aquaculture. In addition, Asia is the most important supplier to the global seafood trade and Asian aquaculture accounts for the majority of the traded seafood commodities.

It is expected that increased population growth and further economic development will lead to increased fish consumption and as a consequence the global demand for food fish is expected to increase by 30 to 40 million tonnes by 2030 from the current level. If the increasing demand for fish is to be met, the continued growth of aquaculture in Asia is absolutely necessary. There are two main reasons for this: the stagnant capture fish production and the dominance of Asia in the global aquaculture industry.

Achieving 60 percent growth in the next 15 years will not only be required for the Asian aquaculture sector to meet the increasing fish demand but will also have enormous implications for the livelihoods of the vast rural population in many Asian countries. Intensification of aquaculture has been the most important factor contributing to the rapid development of aquaculture in Asia. However, although contributing to increased fish production and improved economic efficiency, some intensive aquaculture systems and practices have raised issues of increasing public concern, such as negative environmental impacts, pressure on certain resources e.g. water, land, fish meal etc. and increased vulnerability of small farmers. With the scarcity of such resources, it is impossible to support the desired growth of fish production from the expansion of aquaculture. So, the key is how to achieve sustainable aquaculture intensification.

In order to support the sustainable growth of aquaculture in the Asia-Pacific region, FAO is currently implementing a regional initiative on sustainable intensification of aquaculture (SIA) for blue growth. Recognizing the efforts that have been made in many Asian countries to address the issues related to the sustainability of intensive aquaculture in recent years, and the progress that has been achieved so far, FAO considers documentation and dissemination of existing innovative systems and practices for sustainiable aquaculture production an effective approach to promote SIA in the region. Thus, FAO in collaboration with the Network of Aquaculture Centres in Asia-Pacific (NACA), has initiated a programme to document and disseminate successful SIA practices in the region.

The programme, jointly implemented by FAO and NACA, successfully identified and documented, with the contribution of technical experts in the respective countries, 12 SIA practices that were deemed to have contributed to the sustainability of intensive aquaculture in the Asia-Pacific region. The programme also supported a regional workshop for sharing and validating the documented success stories and for developing an appropriate strategy to scale up these successful practices. This publication includes the 12 documented successful SIA practices, an introduction to the process of selection and documentation, and a synthesis report on the documented success stories. As the first effort of this kind, it is expected that the publication will serve as an important benchmark for successful SIA practices and lessons learned and its wide dissemination will hopefully contribute to the sustainable intensification of aquaculture for regional and global food security and rural livelihoods development.

Kundhavi Kadiresan
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FAO Regional Office for Asia and the Pacific

Preparation of the documents

This publication is the major output of a regional programme jointly implemented by FAO and the Network of Aquaculture Centres in Asia-Pacific (NACA) in 2015 to document and disseminate successful sustainable intensification of aquaculture (SIA) practices in the Asia-Pacific region. The programme is also an important part of FAO's regional initiative on SIA for blue growth in the Asia-Pacific region.

The programme started with the development of the concept of successful SIA practice jointly by FAO and NACA and thereafter NACA member governments and other important aquaculture countries in the region were invited to propose successful SIA practices for documentation in January 2015. A total of 28 proposals was received from 12 countries out of the nearly 20 countries invited. The first joint NACA-FAO meeting was held in late February 2015 to review and screen the proposals received. It was also decided during the meeting that efforts should be made to identify appropriate experts to document a number of well-known SIA practices that have been established and have demonstrated significant merits in contributing to the sustainability of intensive aquaculture in the region. Another meeting of the FAO-NACA work team was held on 1 April 2015 and this finalized the selection of eight country proposals and four FAO-NACA identified SIA practices to be included in the first phase of the documentation exercise. The experts to take charge of authoring the documentation of the individual SIA practices were also identified and appointed at this time.

Following the guideline jointly developed by the FAO-NACA work team and supported by the responsible NACA programme coordinator, Mr Kuldeep K. Lal, the experts completed the first drafts of the documentation through individual or team work in early June 2015 and these drafts were reviewed by Mr Lal and suggestions for modification of the documentation were provided to the authors.

To achieve the main objective of sharing and validating the documented SIA practices among the experts from all the countries in the region and recommending a relevant strategy for dissemination and wider adoption of the documented SIA practices in the region, a regional workshop was convened from 16 to 18 June 2015. Over 30 experts from 17 Asian countries, the South Pacific Commission (SPC), Southeast Asia Fisheries Development Centre (SEAFDEC), NACA and FAO participated in the workshop. All the documented SIA practices were presented by the authors and commented on by the workshop participants. An exercise to assess the documented SIA practices against an SIA scoring matrix jointly developed by FAO-NACA work team was conducted during the workshop and working group discussions on a follow up strategy were held. The results were used as important inputs for the synthesis report included in this publication, which was drafted by Mr Lal and revised by Mr Miao Weimin, the responsible FAO Officer. All the documentation on successful SIA practices was further modified by the authors based the suggestions from the workshop and technically edited by Mr Lal. A professional editor appointed by FAO edited the entire publication prior to printing.

Acknowledgements

The completion of the publication was entirely a result of the joint efforts of all the national experts who documented the selected successful sustainable intensification of aquaculture practices and the NACA-FAO working team. Much gratitude is expressed to Mr Kuldeep Lal who made his best efforts and devoted an enormous amount of time to coordinate the documentation work, organize a regional workshop and draft the executive and synthesis reports in his capacity as the responsible NACA programme coordinator for the joint work. Special thanks are given to Mr Cherdsak Virapat, Director General of NACA and NACA Secretariat staff who supported the documentation exercise and the regional workshop in various ways. Special thanks are due also to Ms Chanphen Bhawangkananth for her assistance in the publication of the document.

Simon Funge-Smith, Senior Fishery Officer, FAO Regional Office for Asia and the Pacific, is gratefully acknowledged for his technical advice to the documentation exercise and the regional workshop.

Executive report

1. Background

The demand for fish in Asia and the Pacific region is estimated to increase by 30 percent by 2030 as a result of the anticipated population growth and the improved living standards of the people of the region. In order to meet such an increased demand for fish, aquaculture production will need to increase by 50–60 percent from the present level by 2030 with the capture fish production remaining static.

Intensification of aquaculture is a major factor that has contributed to the outstanding growth (nearly 10 percent annually) of the aquaculture industry in Asia-Pacific in the past three decades. Such growth has greatly contributed to food security and the nutrition of the people, rural livelihoods and economic growth in the region. The Asia-Pacific region consistently has contributed over 90 percent to the world aquaculture production for decades. In Asia, aquaculture supplies over 60 percent of food fish, comprising over 20 percent of the total protein intake of the Asian population.

The intensification of aquaculture has depended upon new husbandry practices and increased use of inputs and at the same time has raised concerns about the limited availability of such critical resources, disease outbreaks and environment degradation. Unless appropriate corrective measures are implemented, the long-term sustainability of aquaculture growth may not be guaranteed.

The most effective approach to meet the increasing demand for fish is to promote the sustainable intensification of aquaculture (SIA) to achieve blue growth through increasing the productivity and efficiency of aquaculture production while reducing the consumption of resources and negative environmental and social impacts through improved governance, management practices and adoption of innovative technologies.

In order to support sustainable growth of aquaculture for contributing to increased fish supply for food and nutrition, increased livelihood opportunities and overall economic growth in the region, FAO is currently implementing a regional initiative on sustainable intensification of aquaculture for blue growth in Asia-Pacific. Recognizing that various production and management practices have been developed and implemented in the region to achieve sustainable intensification of aquaculture and more generally to develop aquaculture in the region, the documentation and dissemination of successful practices is included as part of the regional initiative.

Sustainable intensification of aquaculture practice as used in this publication is defined as aquaculture production systems or technologies or management practices that contribute to at least one of the followings: (1) improved production and resource use efficiency, namely land, water, feed, and energy; (2) improved environmental benefits; (3) strengthened economic viability and farmers' resilience; and (4) improved social acceptance and equality and do not compromise the rest.

2. Identification and documentation of the successful practices

2.1 Identification SIA practices for documentation

Following the development of the concept note of the programme, which included the definition of a successful SIA practice, a call for proposed successful SIA practices for documentation was prepared and sent to NACA member countries inviting them to participate in the documentation of the SIA process. Following the invitation and follow-up communications, a total of 28 proposals were received from 12 countries.

The proposals were reviewed and discussed during the two joint meetings attended by NACA Director General, coordinators for various NACA programmes and the FAO responsible officer for the programme. Mr Kuldeep K. Lal, the NACA responsible programme coordinator and Mr Miao Weimin, the FAO responsible officer, respectively jointly evaluated the proposals against the criteria for successful SIA practices. The criteria include: improved use of inputs; improved production efficiency; increased socio-economic benefits; improved governance and environmental sustainability. Finally, eight successful SIA practices were selected for documentation and dissemination from the proposals received. It was also agreed that a number of additional recent and important aquaculture developments in the region should be included in the documentation exercise in this first phase of the programme. These recent aquaculture developments include:

1. closed/semi-closed intensive shrimp farming system;
2. development and dissemination of specific pathogen free (SPF) *Paneaus monodon;*
3. development and dissemination of mass seed production technology of grouper in Indonesia;
4. group approach in implementing BMP/GAqP in shrimp farming in India;
5. multi-trophic marine aquaculture system (shrimp-mollusk-seaweed); and
6. improved participation and contribution of women in the process of aquaculture intensification and improved benefits for them.

Through the joint efforts of the NACA Secretariat and the FAO responsible officer, national experts for documenting the eight selected country proposals and four NACA-FAO jointly identified SIA practices were identified and agreed. No appropriate expert was identified for documenting the "Group approach to BMP implementation in shrimp farming in India" and "improved participation and contribution of women in the process of aquaculture intensification and improved benefits for them" so they were dropped for this round of documentation.

2.2 Documentation of selected SIA practices

The guidelines for documenting the selected successful SIA practices were jointly developed by the FAO responsible officer and the NACA programme coordinator and were provided to identified nationals experts for documenting the successful practices. The national experts prepared the full documentation of SIA practices following the guidelines and with technical advice from the NACA programme coordinator and the FAO responsible officer. Most national experts managed to complete and submit the first draft of the documented SIA practice about the deadline of May 25, 2015.

All the articles received from the authors were thoroughly reviewed by Mr Lal and the suggestions for revision of the articles were communicated to the authors. The received articles were also edited by Mr Lal to maintain uniformity. The edited articles were communicated to the authors to cross validate the technical correctness of the editing done at NACA. The articles received from authors were prepared as one single file for circulation during the regional workshop.

2.3 Finalization of the documentation of the SIA practices

The authors modified their manuscripts after the regional workshop based on the comments and suggestions for revision of the manuscripts received during the workshop. The revised manuscripts of individual successful SIA practices submitted by the authors were reviewed further and edited by Mr Lal. All the documentation of SIA practices were edited by a professional editor (contracted by FAO) before they were printed.

3. Regional workshop

3.1 Preparation

Mainly for the purpose of validation and sharing the documented successful SIA practices, a regional workshop was planned as an intergral component of the programme. A workshop prospectus (**Annex I**) with the programme was jointly prepared by FAO responsible officer and NACA responsible programme coordinator. All the leading experts responsible for documenting individual successful SIA practices were invited to participate in the regional workshop. An invitation to participate in the workshop was sent to the NACA Technical Advisory Committee (TAC) member of the NACA member countries that did not contribute a successful SIA practice in this round of documentation. Representatives from Bhutan (the only non-NACA south Asian country) and the South Pacific Commission (SAP, NACA Associate Member) were also invited to participate in the regional workshop.

3.2 Conduct of the workshop

The regional workshop on documentation of successful SIA practices was jointly organized by FAO and NACA in Bangkok, Thailand from 16 to 18 July 2015. A total of 24 delegates (list given as Annex II) participated in the regional workshop. The participants were provided with a compendium of articles on a USB flash drive together with a hard copy of the collection of abstracts of all the manuscripts.

The regional workshop began with a welcome address by Dr Cherdsak Virapat, Director General, Network of Aquaculture Centres in Asia-Pacific and an opening address by Mr Hiroyuki Konuma, FAO Assistant Director-General and Regional Representative for Asia and the Pacific. A presentation introducing the background and process of the documentation of successful SIA practices and the objective of the regional workshop was made by Mr Miao Weimin, the FAO Aquaculture Officer at the Regional Office for Asia and the Pacific, who is responsible for the programme.

Facilitated by Mr Lal, each manuscript author made a presentation on the SIA practice that he/she had documented. Each presentation was followed by discussions and comments and suggestions for further improvement of the manuscripts.

4. Assessment of documented SIA practices and the way forward

4.1 Assessment of documented SIA practices

In order to assess how the documented successful SIA practices are performing in terms of different aspects of sustainable intensification, a simple scoring matrix (Annex III) was developed. The workshop participants were invited to evaluate all the 12 documented SIA practices against the scoring matrix. The results of the assessment exercise were analyzed and synthesized by Mr Lal with technical input from Mr Weimin. The results of the analysis are presented in the synthesis report included in this publication.

4.2 The way forward

To develop a follow up strategy for the SIA documentation and dissemination programme, a working group session involving all the workshop participants and NACA professional staff and Mr Simon Funge-Smith, the FAO Senior Fishery Officer, was conducted. The workshop participants and NACA and FAO staff were divided into three working groups. Each working group focused on suggested improvements of four assigned successful SIA practices and the status, potential and ways to upscale each SIA practice in the region. The outputs of the working group discussions were presented at the plenary session on the last day of the workshop.

The joint FAO-NACA programme to document and disseminate the successful SIA practices in the Asia-Pacific region is the first attempt of this kind. Despite the short time and limited scope for implementation of the programme and difficulty in communication, NACA and FAO were able to identify a reasonably good selection of SIA practices that have ably demonstrated their advantages and benefits in achieving sustainable intensification of aquaculture in the region. The twelve documented successful SIA practices cover the key aspects affecting sustainable intensification of aquaculture: improvement in quality aquaculture inputs for better efficiency; innovative aquaculture production system for sound environmental benefits and new aquaculture planning and management approaches for increased socio-economic benefit in the course of aquaculture intensification. The national experts successfully captured the key elements of individual cases that are of great importance in wide dissemination and further perfection.

Moreover, the regional workshop successfully promoted the awareness of successful SIA practices in the region. The exchange between the experts from different countries and and regional organizations benefited greatly FAO, NACA and the author experts on how to better document and disseminate successful practices. The strategies/approaches recommended by the workshop participants for dissemination of documented SIA practices pointed out the direction for the follow-up of the programme.

4.3 Strategies/approaches for dissemination of documented SIA practices

The twelve documented successful SIA practices have strong potential to improve aquaculture sustainably in the region although they have been developed and practiced in specific countries or even at limited scope at local level. To realize the potential will need strong institutional support at national and local levels. Regional and international organizations also have an important role to play in promoting the dissemination and scaling up of SIA practices by serving as a conduit for the flow of this knowledge and expertise for sharing between countries for mutual benefits. Important strategies recommended by the regional workshop to promote sustainable intensification of aquaculture in the region include the following:

- FAO and NACA to work jointly on the publication of the documented successful SIA practices and support the translation of the publication into local languages and disseminate the successful SIA practices through websites and other social media;
- use regional mechanisms, such as the NACA Governing Council and Technical Advisory Committee meetings, SEAFDEC Council and Programme Steering Committee meetings and ASEAN Sectoral Working Group Meeting etc. to disseminate the documented SIA practices;
- organize more focused workshops at regional and national level and exchange visits and study tours across the countries for sharing knowledge and management practices;
- FAO and NACA to appeal to their member governments to promote SIA practices through developing policy briefs and recommendations;

- encourage the governments to assign responsibility to appropriate agencies for dissemination and promotion of SIA practices and support related capacity building and resource mobilization;
- FAO and NACA to support capacity building at regional and national levels through training, including development of training modules and implementation of training courses for targeted groups;
- FAO and NACA to use South-South cooperation as the platform to promote the dissemination of SIA practices, which can help in resource mobilization and promote a wide range of cooperation between the countries in the region;
- use E-consultation as an important platform for wide exchange among the counries on what SIA practices are available and where they are needed in the region; and
- support pilot projects on field trials and assessment of existing SIA practices and adapting them under different local conditions.

Synthesis report on documented SIA practices

1. Introduction

Sustaining the growth of Asian aquaculture is essential to meet the increasing regional and global demand for food fish in the coming decades. The importance of fish in livelihood and nutritional security, as a diet with health benefits for every country and every strata of human society, ranging from resource poor to rich, is now widely recognized. FAO's Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995) and other documents (FAO, 2008) aim at raising fish production in a sustainable manner and promoting fish consumption by local communities to meet their nutritional needs (see CCRF Articles 2.f and 11.1.9). The rising incomes in the Asia-Pacific region, the most populous region of the world, and the rising awareness of fish as health food are driving the per caput fish demand. To meet this rising demand, an estimated additional 30 to 40 million tonnes of food fish over the present production level by the year 2030 are required and will need to come from aquaculture, as capture fish production is reaching a plateau.

Aquaculture is one of the fastest growing sectors among all the food production systems, growing at an annual rate of approximately 10 percent in the past three decades and currently supplying 50 percent of the global demand for food fish. At present, 90 percent of the global aquaculture production is from Asia where aquaculture intensification has been progressing in the last two decades. This growth of aquaculture was fuelled by intensified use of inputs (materials, energy and investment) and resources (water, land and feed ingredients) and new husbandry practices. However, there are a number of serious concerns regarding the long-term sustainability of the aquaculture sector. The concerns relate to the finite nature of these resources and inputs and their competition with other food production systems, the impact on the environment and biodiversity, new disease outbreaks, biosecurity needs and food safety and socio-economic benefits. In this context, sustainable intensification of aquaculture (SIA) strategies have been recommended in several important forums, such as the FAO-NACA consultation (Miao *et al*., 2014) and APFIC (2014). SIA is oriented towards utilizing technologies for producing more out of fewer resources, with improved governance to achieve minimal impact on the environment and equitable social benefits. Towards SIA goals, the joint programme implemented by FAO and NACA to document and disseminate existing successful SIA practices is a small but effective step to bring together different members from the Asia-Pacific region, for cross learning and mutual support to scale up the successful practices in aquaculture already developed and implemented in some countries of the region.

The joint FAO-NACA programme successfully identified and documented 12 SIA practices that have been implemented at a significant scale and have demonstrated significant merits that contribute to the sustainability of intensified aquaculture in various ways. This synthesis report provides a snapshot of the 12 successful SIA practices and addresses some of the issues related to their dissemination and adoption throughout the Asia-Pacific region.

2. Brief description of successful SIA practices

A number of innovative aquaculture production and management practices have been developed and applied by aquaculture practitioners and managers in the region and fit into the framework of sustainable intensification strategies, which largely result from the significant scientific and technological progress achieved in aquaculture in this region. This presents an opportunity for capacity building and for implementing such useful practices in the production systems of the region. To support this initiative and improve the sustainability of intensive aquaculture, documentation and dissemination of existing successful production and management practices is the focus of this report. The twelve success stories documented by national experts and shared in a regional workshop addressed broadly: improvement in the quality of aquaculture inputs for improved production efficiency, increased socio-economic benefits of aquaculture and better planning and management of aquaculture for environmental sustainability. These documented practices comply with several recommendations for strengthening SIA made by APFIC (2014). In view of this, the practices documented here are highly promising for improving sustainable aquaculture production throughout the region.

Therefore, developing a road map supported with pilot programmes is the immediate next step for scaling up and adoption by the different stakeholders in the region. The pilot level programmes will play a crucial role in multilocational trials, to incorporate the customization of the available practices to suit the local conditions and the required capacity building. The brief summary of each documented successful practice and the prospective way forward is synthesised and presented below. The practices on the genetic improvement of common carp and rohu are similar in their objectives and hence the way forward for each is addressed under a single heading. (see 2.3)

2.1 Development of improved common carp strain and its dissemination in China

Description of practice: The Freshwater Fisheries Research Centre (FFRC) of the Chinese Academy of Fishery Sciences (CAFS) developed an improved strain of common carp, named the FFRC strain of common carp, by crossing the Jian carp and Huanghe carp strains after four generations of selective breeding programmes. The FFRC strain achieved a cumulative direct genetic gain of 28 percent during the selection process. On-farm testing of the FFRC strain in three locations of China showed that the FFRC strain had 20.10 percent to 39.19 percent superiority compared to the control lines under different environmental conditions. The demonstration and dissemination of the FFRC strain common carp was achieved through the platform of the Chinese Modern Agro-industry Technology Research System, which consists of 25 research stations and 30 experimental stations distributed throughout the country. After demonstration, an integrated amplification and dissemination system was established to produce a large quantity of high quality seed of the FFRC strain of common carp. At present, the FFRC strain of common carp has been disseminated to a total of 20 provinces out of 31 provinces on the mainland China. The total dissemination area is 40 thousand hectares and the production value increased by more than USD80 million.

2.2 Development and dissemination of genetically improved "Jayanti" rohu (*Labeo rohita*)

Description of practice: Improved rohu or "Jayanti rohu" was developed through selective breeding and after eight generations of selection, 18 percent higher growth per generation was achieved. The field testing of Jayanti rohu was carried out in four different states of India and yielded encouraging results. Disease resistance against *A. hydrophila* was also added as a second trait of selection to the ongoing rohu breeding programme. After mass challenge, two lines of rohu have been produced, namely a resistant line and a susceptible line. The resistant line rohu showed significantly higher survival over the susceptible line. Disease resistant rohu is under field trial at present. Genetically improved Jayanti rohu for growth has been disseminated to different states in India with a high rate of acceptance by the fish farmers and hatchery owners. In India, 16 states have already received Jayanti rohu from the nucleus center, CIFA, as well as different multiplier units. The improved rohu has proved to be feed neutral and effective under all the normal culture practices and this has enhanced the rate of acceptance. An impact assessment further confirmed the superiority of the Jayanti rohu over the normal rohu. The yield with Jayanti rohu increased by

23 percent over normal rohu in the farmers' fields. The cost of production has reduced 26.6 percent as the rearing period was reduced by 53 days in a crop.

2.3 The way forward for improved common carp strain and improved Jayanti rohu

On the whole, the aquaculture sector still uses wild genotypes and improved domesticated varieties contribute only 8.2 percent of the total used. Two species, *Cyprinus carpio* (China) and *Labeo rohita* (India), have been genetically improved with the potential of enhancing yield by 20 percent to 25 percent and the improved varieties have been proven in country field trials. The two fish species already exist as naturalized aquaculture species in the Asia-Pacific countries. These are important for family level nutritional security as almost the total production is consumed within the countries producing them (only 8 percent of the total production of *L. rohita* is exported from Myanmar). These species are cultured in small and large scale commercial ventures. Since this genetic improvement is the outcome of a long-term process, enhancing the culture area will have direct benefit to consumers and producers. There is need for strategic planning through an evaluation process in different countries to facilitate germplasm transfers conforming to international policies. This will also require capacity building plans in the receiving countries so that genetic gains accumulated are sustained or increased. This also gives an opportunity for improving local naturalized feral populations to retain the benefits of accumulated adaptations. These two SIA practices have a strong potential for being scaled up and disseminated in the Asia-Pacific region and for improving productivity. This can be achieved best through establishing networks and collaborative projects.

2.4 Development and dissemination of SPF shrimp seed (*Penaeus monodon*) in Thailand

Description of practice: The selective breeding programme for specific pathogen-free (SPF) black tiger shrimp, *Penaeus monodon*, aimed at producing fast-growing and disease-resistant SPF *P. monodon* seed for farmers. The shrimp growth rate has been improved in every succeeding generation and families with relative resistance against WSSV have been identified. From the sixth generation of the broodstock onward, the seed was disseminated to farmers by setting up a commercial broodstock multiplication centre (BMC) of SPF *P. monodon* broodstock. A commercial hatchery was also set up to produce high-quality SPF seed. Grow-out farms stocking the shrimp seed experienced both failure and success. Crop failure mostly happened because of mass mortality from Acute Hepatopancreatic Necrosis Disease and, to a lesser extent, White Spot Disease. In the successful crop, growth rate and survival of the shrimp grown from the SPF seeds were satisfactory. Most successful farms combined a number of eco-friendly techniques to prevent the diseases, especially biosecurity, biofloc technology and co-culture with tilapia.

The way forward: *P. monodon* culture, which is considered a premier commodity among consumers, has succumbed to the shift in production of exotic whiteleg shrimp. The practice developed in Thailand of selectively bred *P. monodon* and production of SPF broodstock has the potential of being disseminated to other countries to improve their own native *P. monodon*. This will offer a suitable alternative to whiteleg shrimp for aquaculture with reduced disease risk. Although such facilities are infrastructure and resource intensive, the production of SPF broodstock will enhance aquaculture sustainability if countries develop their own capacity with expertise from Thailand or even undertake the development work as a group of countries that share political will and geographical regions, or encourage public-private participation.

2.5 Successful development and dissemination of the mass grouper seed production technology in Indonesia

Description of practice: The hatchery techniques to produce grouper seed on a commercial scale were developed by Gondol Research and Development Institute for Mariculture (GRDIM). The practices, which addressed broodstock maintenance, spawning, larval rearing and nursery culture have been adopted widely by the private sector and government hatcheries for several grouper species such as humpback grouper, *Cromileptes artivelis*, tiger grouper, *Epinephelus fuscoguttatus,* flowery grouper, *E. polyphekadion*, estuarine grouper, *E. coioides*, coral grouper, *E. corallicola*, potato grouper, *E. tukula*, giant grouper*, E. lanceolatu*s, coral trout, *Pletropomus leopardus* and also grouper hybrids, e.g. crossing between male *E. lanceolatus* × female *E. fuscoguttatus* and crossing between female *E. fuscoguttatus* × *male E. polyphekadion*. Two types of hatcheries developed by GRDIM are the complete hatchery (CH) and the backyard hatchery (BH). At present, there are 21 units of CHs and 536 units of BHs surrounding GRIM and CADC-Situbondo, and these have provided jobs and income for 2 000 people. Production of grouper seed for various species ranged between of 12 and 20 million/year and almost 90 percent of the seeds was exported to neighbouring countries. Groupers seed production research should be assigned a priority so as to continue refining the already developed technologies, developing standardized methodologies and techniques for domesticating groupers and developing vaccines for the treatment of viruses.

The way forward: Groupers are turning into a widely accepted commodity for culture in this region. Their culture is not able to reach its potential in many countries because of the lack of hatchery technology. This also puts pressure on natural seed resources. The expertise from Indonesia is remarkable as it has closed the life cycle of several grouper species. This could help many countries to develop their own seed from native broodstock, which is more sustainable and also offers opportunities for propagation of assisted stock replenishment in nature without risk to the native genetic diversity. It is further noted that the same facility is used for milkfish seed production. Therefore, it may open opportunities for more diversification by countries if Indonesia expertise and know-how is adopted.

2.6 Development and dissemination of low-cost farm-made formulated feed for improved production efficiency in polyculture

Description of practice: Extensive brackishwater farming systems that depend upon natural seeds and natural productivity with multiple species were improved to achieve sustainable higher production by the Central Institute of Brackishwater Aquaculture (CIBA), India using low-cost farm-made feed made from locally available ingredients. Experiments in indoor systems on-farm and at farmer's ponds with polyculture using indigenous brackishwater fish and shrimp species using low-cost farm-made feed yielded an FCR of 1.36 in three consecutive trials of 325 days in farmers' ponds. The farm-made feed (crude protein – 29.77 percent) containing different unconventional ingredients (sunflower cake, mung husk) with 10 percent fishmeal performed at par with that of feed containing 22 percent fishmeal used in farmers' ponds. Economic analysis revealed a net profit of about USD4 693.5/ha with a cost-benefit ratio of 1.85. A production improvement of twofold to fourfold compared to conventional systems was observed and this improved polyculture practice was disseminated to 57 farmers in West Bengal, India covering 30 ha. To cater to the increased demand for farm-made feed, the farmers formed a cooperative society which established the necessary infrastructure with financial help from the State.

The way forward: The success of the low-cost feed development for brackishwater polyculture exhibited a small but unique intervention with economic gain for small-scale farmers in sensitive and fragile ecosystems. Nevertheless, it should not be seen as a replacement for the usual brackishwater practices as although this may present an opportunity to improve the livelihoods of farmers engaged in extensive farming, intensive fish culture may not be environment friendly in areas such as mangroves. This knowledge could be shared with other parts of India as well as countries such as Myanmar, Bangladesh, and Pakistan, even Pacific Island countries and others in Southeast Asia that share similar aquaculture practices and may have similar types of low-cost ingredients. Such a practice can undergo small science-based adaptations when shared with other countries with respect to the use of local ingredients. But such a practice needs careful dissemination and adequate study on local ingredients as with regular use, the inexpensive ingredients may become expensive. Therefore, such risks need to be considered before wide scale adoption. It was observed that this practice is easy to adopt in local contexts by rural small-scale farmers, is suitable for small-scale operations and has the potential for improving incomes as well as providing healthy food to rural households in an environment friendly manner.

2.7 Increase resilience and empowerment of small aqua farmers through cooperatives

Description of practice: Erhu town took the black carp as the breakthrough point for modernizing the aquaculture industry through the establishment of the Ganlu Black Carp Cooperative. As a managerial and social practice, the cooperative has promoted sound environmental benefits, provided economic viability, farmers' resilience and social acceptance of intensive/semi-intensive aquaculture while enhancing the productivity and improving resource use efficiency through large-scale aquaculture. Under the Ganlu Black Carp Cooperative, the aquaculture area increased to 153 ha for black carp, with 110 member farmers producing 1 100 tonnes of black carp in 2014. The output value of aquatic products in the town was CNY123 million. The cooperative has greatly controlled the cost of production, quality management and the marketing of black carp, as well as led to better economic return to each farmer and successfully increased the resilience and empowerment of small aquafarmers.

The way forward: The success of the Ganlu black carp shows how a common locally consumed commodity can have a pan national presence and demand, with the systematic adoption of new concepts of management, marketing, input supply and e-commerce, combined with the traditional concept of grouping farmers into a cooperative. However, such models also work because of certain favourable local conditions. Therefore, a carefully framed strategy of dissemination of such experience within China and outside in the Asia-Pacific region could empower small-scale farmers. The strengths of this SIA practice are its spirit of encouraging collective efforts to purchase inputs and undertake marketing, the premium price obtained for black carp products, the linkage between government and the cooperative and the benefits to be gained in collective strength, especially in marketing for small-scale farmers. However, locally appropriate adaptations may be necessary to suit local conditions at the time of adoption.

2.8 Development of bivalve farming as a source of income generation for women's self-help groups in coastal India

Description of practice: Innovations in existing bivalve farming technologies simplified them, and this resulted in an increase in profitability and made them attractive to farmers. During this process, the entire gamut of bivalve farming operations such as site identification, seed and spatfall calendars, remote setting, mechanization in seeding and harvesting, quality and depuration protocols, ready-to-eat and ready-to-cook products, organic farming protocols and environmental impact assessments were worked out. The success in commercializing the technologies was mainly a result of a unique synergy that was actively pursued and developed by technology developers, promoters, and financers.

The new bivalve farming was taken up primarily by women, especially those belonging to women's self-help groups, and the number of farmers adopting the technology reached 7 000 and the highest production of over 20 000 tonnes was achieved during 2009 making India one of the top ten bivalve farming countries in Asia.

This development of bivalve technology can be adopted by other states and developing nations where a similar hydrological, social, and market environment exists.

The way forward: The bivalve farming for empowering women in coastal India is the outcome of systematic innovations in the existing technology. All the interrelated components enabled an increase in bivalve production and led to a large number of farmers adopting the new technology. It is a niche kind of practice and can be adopted in similar conditions in South Asia and Southeast Asia. Although the simple technology used had a special appeal to women, it is in fact gender neutral. It has enormous potential for encouraging the formation of groups for collective action, including the adoption of new technologies, and should be able to attract funding from financial institutions. Adoption of this technology by different countries will also require adaptations to suit local contexts and this will need the involvement of local research institutes and could benefit from sharing Indian expertise.

2.9 Integrated rural livelihood development through trout farming and related businesses in mountain and Himalayan areas

Description of practice: The successful dissemination of rainbow trout culture technology has led to its expansion in the mountainous and Himalayan regions of Nepal. Out of a potential 54 districts, 21 districts have already started practicing rainbow trout farming. There are about 90 farmers, producing nearly 236 metric tonnes of trout from an area of 140 000 m^2 with an average productivity of 168 metric tonnes/ha. The farmers produce an adequate amount of seed and feed using mostly locally available ingredients. The net benefit of trout farming was estimated as nearly USD6/m^2. Therefore, farmers with small landholdings could make a good living from the business. In addition, most of the trout farms are integrated with restaurants to add value and generate more income. Trout farming is completely feed based and there is lot of effluent coming out of the system, but this is used for vegetable farming so does not create a problem. Trout farming has utilized the otherwise unused land resources efficiently to produce nutritious food, and improve the incomes and livelihoods of rural farmers.

The way forward: The integration of trout farming in Nepal with the use of local feed and the establishment of a value chain for local consumption is a useful niche experience and constitutes a demonstrable example for adoption in adjoining countries for improving the livelihoods of native communities. However, potential environmental impacts of promoting an exotic fish in the fragile mountain ecosystem may need to be assessed. Such an SIA practice can be even run by a family as well as a small-scale or large-scale business, integrated with other agriculture activities, and especially linked with hotel/restaurant/tourism business for ready markets and can fetch a good price and excellent economic returns. The availability of quality trout seed may be a constraint in the widespread adoption of this SIA practice.

2.10 A science-based management approach for sustainable marine cage culture

Description of practice: The WATERMAN system exhibits a unique integration of mathematical modelling and field studies, and provides a quantitative determination of the carrying capacity of existing and potential FCZs in Hong Kong SAR. Using WATERMAN, the carrying capacities of all the existing FCZs in Hong Kong SAR were determined. Based on the findings and taking into consideration other factors, the Agriculture, Fisheries and Conservation Department (AFCD) recently launched a pilot scheme to issue new marine fish culture licences for fishermen to practice mariculture in three FCZs having surplus carrying capacity. On the other hand, the WATERMAN system also identified some overloaded FCZs, suggesting a need to reduce the stocking volume and/or increase the culture area. The WATERMAN system was also used to help identify potential new sites for fish farming, thereby strengthening the sustainable development of mariculture in Hong Kong SAR.

The way forward: The WATERMAN system is a development from Hong Kong SAR China and is an outcome of a long systematic, interdisciplinary research project and has been adopted in the country at policy level. This may have a vast potential for adoption and learning in several countries that are attempting to expand mariculture. Furthermore, this SIA practice has a strong scientific and mathematical component developed over the years and has reached the stage of implementation. The output of implementation is very important. There is a need to develop an appropriate roadmap, for fitting this practice into the local contexts and environment, which may differ from country to country. There may be need to develop further standard procedures for adaptation and adoption to different environments. However, a critical aspect of this implementation will be the level of accessible data on marine ecosystems available in different countries or countries can start accumulating data that can be synthesized for implementation of this technology.

2.11 Integrated multi-trophic aquaculture of fish, bivalves and seaweed in Sanggou Bay

Description of practice: Integrated multi-trophic mariculture with finfish, bivalves and seaweed in Sanggou Bay, northern coast of China, was successfully implemented. In this IMTA system of finfish, bivalves and seaweed, bivalves function as a filter to remove the suspended particulate organic materials, which originate from fish faeces, small size residual feed and phytoplankton. The work focussed on appropriate integrated species selection through understanding if the bivalves could utilize the waste particulates, which kind of bivalves had higher efficiency and what are the optimal co-culture densities of fish, seaweed and bivalves, which are based on the efficiency of wastes removal.

The way forward: Integrated multi-trophic aquaculture practice is a demonstrated success story from Hong Kong SAR that can be shared with the countries interested in mariculture. It has been demonstrated and implemented on a relatively large scale. There is a need to establish a detailed rationale for choosing extractive species/varieties (possible alternative species of seaweed and mollusks, sea cucumbers and seaweed etc.) and stocking ratios of different commodities as well as criteria for making judgements. The impact of integration on animal health especially under cage culture needs to be studied. Such information will help the local research institutes to facilitate the adoption of the practice in accordance with local conditions, species availability, and market demands prevailing in different countries.

2.12 Sustainable milkfish production in marine cages in the Philippines through strong government support and effective public-private partnerships

Description of practice: The practice of sustainable intensification of milkfish aquaculture in marine fish cages under semi-intensive grow-out conditions in the Panabo City Mariculture Park (PCMP) in Davao del Norte, Philippines was established in 2006. The practice was so successful that in just five years it became the third largest among the 63 operational mariculture parks in the Philippines in 2011, with 86 private investors-locators operating a total of 322 units of cages. At present, a total of 372 units of fish cages are operating in the mariculture park (MP). The success is attributed to the effective partnerships between the government (both local and national) and the private sector. The comprehensive MP City Ordinance that governs the PCMP is strictly implemented. The national government, through the Bureau of Fisheries and Aquatic Resources-National Mariculture Centre (BFAR-NMC) provides technical support in all aspects from stocking to harvesting during the production cycle. Workers are trained and organized into groups by BFAR-NMC such as caretakers, cage framers, netters, harvesters, fish processors, and others, and actively participate in discussions related to MP operations to ensure protocols are properly followed. Harvesting of stocks are done by skilled workers trained by BFAR-NMC, all done in the "Bagsakan Center" or fish landing area and are well-coordinated.

The way forward: Sustainable milkfish production in marine cages in the Philippines has been a success story of improving livelihoods through strategic involvement of the government and the public and has potential to be replicated in other countries. The strength of this successful SIA is not only the management approaches adopted but the cohesive functioning of different components including technical components, the management of cooperatives and also the individual farmers. The capacity of the agencies that are doing technical monitoring is very important. Another important aspect of this story is having a successful management team as it controlled skilled manpower from cage maintenance to harvesting. Through the control of this manpower and making it available at the appropriate time, the management controlled the carrying capacity, harvest, flow of harvest into the market to control the price for the ultimate benefit of farmers. These lessons can be learned and disseminated in different countries for management of the culture of their own species and an example of government intervention and the strength of cooperatives.

2.13 Development and dissemination of closed (semi-closed) intensive shrimp farming system in Thailand

Description of practice: The shrimp industry of Thailand benefited from closed intensive shrimp farming and created an export income of over USD3 000 million annually. The key factors in its success are the technology development and inputs for shrimp farmers to improve efficiency in their farm management such as hatchery technology, formulated feed and material supply, aeration and water exchange, low water exchange technology, specific pathogen free (SPF) shrimp, biosecurity and disinfection, genetic improvement programme, probiotics and automatic feeder development. The threat to the high potential of closed intensive shrimp farming from emerging diseases especially the last outbreak of EMS/AHPND comes from the accumulation of organic wastes. This outbreak made significant losses and discouraged farmers to adopt the new technology and farm management concepts. The balance between economic growth in the shrimp farming sector and the availability of quality critical inputs and technology need to be well managed for future sustainability.

The way forward: The success of this shrimp farming system in Thailand is a result of the combination of an eco-friendly approach with closed intensive production. This SIA practice with whiteleg shrimp is important for many shrimp producing countries and can be a useful opportunity for capacity building and replicating. There is need for creating awareness on the advantages of and reasons for closed water culture systems to improve its chances of adoption. In the future it will be useful to study this closed culture system with seaweed and bivalves and also study the role of beneficial microbes.

3. Significant drivers in the successful development and adoption of SIA practices

The twelve successful SIA practices documented here are quite diverse in the origin and genesis of problems addressed, the target objectives, and scale of operation. Nevertheless, all these cases have demonstrated successfully the significant environmental and socio-economic benefits and attributes required for sustainability of aquaculture. An analytical synthesis across these SIA practices revealed certain common drivers that played a significant role in the successful adoption in their country of origin. A review of such drivers is very important so that these SIA practices can be disseminated and adopted for the benefit of rural small-scale farmers at regional level. Such a review can also appraise policy-makers of the need to establish prerequisite frameworks that facilitate the development of new SIA practices and their dissemination. The following drivers are identified as the most important factors that have contributed to the success of the SIA practices presented here.

3.1 Market demand drives innovative aquaculture technologies and production practices

All the SIA documented practices pinpoint that the species for developing SIA practices is determined by market demand, which gives ready and high volume trade opportunities. Common carp, rohu, grouper, milk fish, black carp shrimps and bivalves are among the commodities that are in high demand for local consumption or provide attractive export earnings. Therefore, aquaculture commodities that contribute to nutritional and livelihood needs of a large section of society, at national, regional or global level, might receive priority from the governments and the aquaculture sector to address issues related to their sustainable production growth.

3.2 Available technical capacity for research

Targeted research is a critical component in the development of successful SIA practices and a final outcome could be based on the experience from several unsuccessful trials. Available technical research capacity including trained manpower and basic infrastructure within the nation or region or through an expert collaboration is very important for leading the process of SIA development and adoption to success. All the documented SIA practices show that a considerable component of research and innovation had been taken up before the SIA practices became acceptable for adoption by stakeholders. This documentation process also gives an opportunity for expertise available within the region in many areas such as genetic improvement and aquaculture management aspects, which can be used to build capacity in other nations in the region.

3.3 Available background knowledge and data

The knowledge and data available on species, species biology, husbandry practices, socio-economic relevance and environment, can help to accelerate the process of developing SIA practices. Such background knowledge will also help in considering the potential of undertaking research on SIA practice development for policy and funding support. For example, without the prior information on biology and captive propagation technology already available for common carp, rohu, grouper, brackishwater polyculture and shrimps, the genetic improvement, seed and feed development programme would not have been possible. Similarly, the available production systems for black carp, milkfish and bivalves have been customized in innovative ways to raise production with stakeholder's involvement. It is also understood that the documented mariculture SIA practices herein are based on the data available for over at least a decade.

3.4 Continuous funding support for research and dissemination

Access to adequate funds through public or private supported research programmes is essential for the development of SIA practices that can benefit society on a large scale. Many of the documented SIA practices are the outcome of programmes that are time and resource intensive. The innovations incorporated into the development of practices to ensure that they meet the farmers' needs in a cost-effective manner require a significant research component. The importance of this factor is unambiguous in the twelve documented practices, which were originally carried out in one or several projects by public supported research organizations. Timely and adequate financial support to disseminate the research outputs effectively to a large number of farmers is extremely important to translate the research results into real social benefits.

3.5 Strong administrative will and a conducive environment

Without administrative will it is not possible to provide a conducive environment and allocate resources for research, innovation, and the upscaling of the SIA practices. The direct involvement of administration in supporting and producing a cohesive environment is apparent in the documented SIA cases, especially for the establishment of cooperatives in China, bivalve farming in India, cage culture of milkfish in Philippines and seed production of groupers. Other SIA successes documented here would not have been undertaken without the strong and focussed administrative support from the countries concerned.

3.6 Long-term vision in strategic planning

The countries develop action plans and strategies individually or based on global inputs such as the Code of Conduct for Responsible Fisheries, strategic action plans on SIA, guided by FAO and obligations under the CBD. Such action plans are implemented with the long-term vision to uplift socio-economic conditions of the populations, through one or more programmes. Envisioning the genetic improvement of important species for aquaculture, as documented here, is an example for such visionary action plans. Similarly, other SIA successes are also the result of research carried out over decades. All these cases show that there is always a need for an action plan that embodies a vision from practice development to its dissemination and large-scale adoption and possible provision of benefits to stakeholders.

3.7 Prospective benefits to society

Identifying the prospective benefits that can be available to a large section of the society can play an important role in the development of administrative will and supportive policies. These can lead to a conducive environment and adequate resources for the endeavour. This factor contributed very significantly to these documented practices. Indeed all of the practices realized the socio-economic benefits of aquaculture and the improved planning and management of aquaculture.

3.8 Demonstrated output

The demonstrated output coming from the practices developed out of research with stakeholder's involvement is very crucial for large-scale adoption and implementing dissemination plans. The demonstrated success encourages financial organizations and policy-makers to provide resources for enhancing the use of SIA practices. The primarily research-based cases such as genetic improvement, grouper seed, SPF *Peneaus monodon* and the two mariculture cases demonstrated the positive socio-economic benefits through impact assessment before these could be acceptable for large-scale use in aquaculture. It is very clear that unless the envisaged societal benefits of SIA practices are demonstrated clearly and doumented, the dissemination for scaling up the practices may not be possible.

4. Assessment of documented SIA practices

In general, all the 12 documented SIA practices are in alignment with the overall principle of the sustainable intensification of aquaculture and have all demonstrated merits in contributing to the sustainability of intensified aquaculture in one or more ways. However, each of the 12 documented practices basically focus on a specific issue related to sustainable intensification. Therefore, their performance in terms of achieving sustainability in the different dimensions of sustainable intensification (production and resource use efficiency, environmental sustainability and socio-economic equality) vary significantly. In order to have a comprehensive picture of how the documented practices fit into the overall framework of SIA, a small assessment exercise was conducted during the regional workshop.

A scoring matrix for assessing the permanency of documented SIA practices was developed jointly by FAO and NACA (see Annex III). All the regional workshop participants were invited to participate in the scoring exercise. The response score of the delegates was prepared as a excel spreadsheet and analyzed.

The aggregated scoring results for the 12 documented SIA practices are presented in Table 1. The analysis shows that, overall, the 12 documented SIA practices received the mean score of 3.0 out of the full score of 4.0. This assessment result indicates that the twelve practices adhered to the SIA practice norms generally. It also showed the need for further efforts to improve and scale up the documented practices in the region for enhancing aquaculture production sustainably and realizing greater socio-economic benefits. There may be a need for considering ways to improve environmental sustainability especially in terms of a criterion such as effluent discharge control. It is encouraging to see that there is a perception of improving socio-economic aspects, economic returns and governance mechanisms through the use of these SIA practices.

Table 1 Mean scores for SIA activities for the practices presented during the workshop

Dimension	Score for individual element					Overall score for dimension
Environmental sustainability	**Effluent discharge**	**Sustainable use of water & space**	**Biosecurity**	**Aquatic biodiversity**		**Environmental sustainability**
	2.5	2.8	2.7	2.7		2.7
Social acceptability	**Gender equity**	**Small holders benefit**	**Social harmony (conflict solving)**	**Job opportunity**	**Food safety and quality**	**Social acceptability**
	2.8	3.1	2.9	3.1	2.9	3.0
Production efficiency	**Output per unit water body**	**Economic return to investment**	**Efficiency in feed use**			**Production efficiency**
	2.9	3.0	2.9			2.9
Good governance	**Regulation**	**Planning**				**Good governance**
	3.0	3.0				3.0
		Overall mean score for SIA*				2.9

* Based on the 12 SIA practices and the responses of 24 participants.

5. Epilogue

The practices documented through the joint FAO-NACA initiative present significant efforts that have been made by governments and sectoral stakeholders in the region in promoting the sustainable intensification of aquaculture. These efforts were based on using scientific knowledge and harmonizing science with grassroots level farmers' practices and supportive policies and financial systems. The SIA practices have been the outcome of significant investments made in research, planning, capacity building by the respective countries and therefore the experience gained from such efforts is extremely valuable for the future of aquaculture. Nevertheless, these practices have proved their success already in their countries of origin. Establishing a network can make such gains a reality for other countries in the region. This can greatly save resources as other countries will not need to invest to the same extent in the development of similar practices. Through this exercise, proven methodologies are now available for adoption and taking aquaculture forward. The successful SIA practices that have been evolved and applied at local levels in different countries have a strong potential to improve aquaculture sustainably in the region. This will need strong institutional involvement not only at the national level. It will also require regional and international organizations to serve as conduits for the flow of this knowledge and expertise for sharing between countries for mutual benefit.

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Country Paper 1: Development of an improved common carp strain and its dissemination in China

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Abstract

A breeding programme for common carp improvement was conducted at the Freshwater Fisheries Research Centre (FFRC) of the Chinese Academy of Fishery Sciences (CAFS). The origin of the synthetic base population was formed from a complete diallel cross involving the Jian carp and Huanghe carp strains. The selection was performed using the family selection procedure combined with a quantitative genetic analysis. The broodstock for the next generation was selected based on the high estimated breeding value (EBV) of each individual from different families, but mating of close relatives was avoided to control inbreeding. The improved strain, herein named FFRC strain common carp was obtained after four generations of selection. FFRC strain achieved a cumulative direct genetic gain of 28 percent, averaging 7 percent per generation during the selection process. On-farm testing of the FFRC strain in three locations in China showed no interaction between genotype and environment because the FFRC strain had 20.10 percent to 39.19 percent superiority compared to the control lines under the three environmental conditions. The demonstration and dissemination of the FFRC strain common carp relied on the platform of the Chinese Modern Agro-industry Technology Research System. After demonstration, an integrated amplification and dissemination system was established to produce a large quantity of high quality seed of the FFRC strain common carp. The genetic breeding centre of the FFRC strain common carp provided to the hatchery two families of improved broodstocks with high EBV coming among the top ten and a distant interfamilial genetic relationship. The fries and fingerlings produced by the hatcheries were then disseminated to the farmers in local provinces or neighbouring provinces. At present, the FFRC strain common carp has been disseminated to a total of 20 provinces out of 31 provinces in mainland China. The total dissemination area is 40 thousand hectares and the production value increased more than USD80 million.

Introduction

Common carp (*Cyprinus carpio* L.) is one of the most economically important freshwater species for aquaculture in the world including China (FAO, 2012). In China it is the third most important cultured finfish alongside grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*). In 2011, the production of cultured common carp reached 2.71 million tonnes and accounted for 11 percent of the total inland aquaculture production in China (TFBMA, 2012).

The common carp is widely distributed throughout the country with distinct morphological and genetic variations that might be the outcome of natural selection and artificial breeding. The most popular wild and domesticated common carp populations in China include Huanghe carp (*C. carpio haematopterus* Temminck et Schlegel), Heilongjiang carp (*C. carpio haematopterus*), purse red carp (*C. carpio var. wuyuanensis*) and Xingguo red carp (*C. carpio var. xingguonensis*). Accordng to Balon (1995), China has a long history of culturing common carp and the species has played a significant socio-economic role in Chinese society. However, the breeding programmes for this species only started during the 1970s and some varieties were developed for aquaculture, mainly through the use of crossbreeding techniques (Dong and Yuan, 2002). Jian carp (*C. carpio* var. *jian*), which was bred by scientists in the FFRC of the Chinese Academy of Fishery Sciences in the 1990s, is the first variety of common carp that was produced through artificial breeding in China. The techniques used to produce this variety include hybridization, within-family selection and gynogenesis. The gross production of Jian carp is about 30 percent higher than other varieties of common carp (Dong and Yuan 2002).

Because of the superiority of the Jian carp, a family selective breeding programme was conducted at FFRC to further improve quality and growth performance of this strain. We followed the method used for other aquatic animal species and established a synthetic base population from different varieties. Subsequently, with the animal mixed model, we ranked candidates for selection based on their estimated breeding values with the aim of identifying and selecting superior animals to be used as parents of the next generation. This approach has been applied successfully to improve the productivity of several terrestrial farmed animals (Gianola and Rosa, 2014) and aquaculture species (Gjedrem, 2012). Experimental studies of common carp also report that selection for increased body weight resulted in significant improvement in growth performance (Vandeputte *et al*., 2008) and also brought about a correlated increase in body traits (e.g. body length) (Ninh *et al*., 2013). However, possible changes in fitness related traits such as survival during grow-out have not been reported in this species.

1. Process of genetic improvement

The breeding programme for common carp was conducted at the Freshwater Fisheries Research Centre (FFRC), a part of the Chinese Academy of Fishery Sciences (CAFS). FFRC is located in Wuxi City adjacent to Lake Tai, which is the third largest freshwater lake in China and is about 30 km to the south of the Yangtze River. The area falls in the temperate climate zone with typical seasonal temperature changes. The annual temperature ranges between -7^{o}C and 38^{o}C (the average temperature is 16.2^{o}C). The average annual rainfall is about 1 000 mm. Topographically, FFRC is located in low plain areas (200 m above sea level) along the lower reaches of the Yangtze River. The water table is pure freshwater with pH 7.2 to 8.5 and the salinity level is below 0.2 ppt.

1.1 Family production and rearing of the base population

The synthetic base population was formed from a complete diallel cross involving the Jian carp and Huanghe carp strains. In this experiment, 78 families were tagged and reared for about 20 months. Measurements of body weight, length and height were recorded for all the PIT (Passive Integrated Transponder) tagged fish. The data obtained for this base population was analyzed to estimate breeding values and used to carry out the first round of selection. The candidate spawners in each generation were reared in separate earthen ponds at a low stocking density (3 000/ha). The spawners were fed intensively twice a day with pellet feed that was specifically formulated for common carp (30 percent protein and 3 percent lipid) and was used throughout the rearing period. The parent breeders in each generation were paired, based on their EBV and their relationship with other individuals in the pedigree. Sexually matured breeders were selected through visual examination during the spawning season (April to May) and subjected to hormonal intervention 500 IU HCG + 4 mg LRH-A2 per kg BW for females and half of this dose for males. Each pair (family) of the injected fish was then released for natural spawning into an individual hapa (a net cage) ($1 \times 1 \times 1$ m^3, 40 mesh per inch) installed in two earthen ponds. Spawning occurred about 12 hours after the injection. After 12 hours of spawning, the hapas with eggs were transferred to the egg-hatching site. The hatching hapas were of $1 \times 1 \times 1$ m^3 (20 mesh per inch) installed in indoor cement tanks (70 m^3). Twenty hapas were installed in each tank. Eggs hatched after about 48 hours. The eggs for each family were separately reared in different hapas. One week after spawning, the fish larvae were transferred to cages with larger mesh size (20 mesh per inch) at a fry-rearing site in an earthen pond of 0.35 ha, about 2 m deep. The stocking density in the cage was 1 000 individuals per m^3. Fish larvae were fed with soybean milk and fine granular formulated feed. After the larvae attained 3 mm in length, they were again moved to cages with larger mesh size (3 mm mesh size). The stocking density was reduced to 100 individuals per m^3. For each family, only about 100 of the largest individuals were retained and restocked in the new cage and the rest were culled. The fish were reared in the same cage and were fed with pellet feed (32 percent protein and 3 percent lipid) until tagging. During this period, the fish were fed twice a day at the feeding rate of 2 percent to 4 percent of the body weight and adjusted according to ambient temperature.

1.2. Individual tagging

The fish were tagged after about two months of rearing. The tagging of all the families was completed within two days. In each family, 50 randomly sampled fingerlings were tagged with a passive integrated transponder (PIT) for individual identification. At tagging, body weight and body length were recorded for individual fish. For the tagged fish, the average body weight at tagging was 20 g and the average body length was 93.5 mm. The tagged fish were temporarily kept for observation in indoor cement tanks for one to two weeks before being released into an earthen pond for further rearing. Normal feeding was resumed one day after the tagging. During this period a small proportion of fish died or lost their tag (about 0.1 percent). In families in which mortality and loss of tag had occurred, extra fish were tagged and added as replacements.

1.3 Communal rearing

Communal testing of all the families was conducted in two different stages with a total duration of 435 days. During the first phase of communal testing, all the tagged fish were released into one earthen pond of 0.16 ha and a depth of 1.8 m, after the temporary holding. The fish were fed with pellet feed (30 percent protein and 3 percent lipid) daily, during early morning and late afternoon. The stocking density in this period was maintained at 18 000 fish per ha. The water temperature was generally below 25°C. During the second phase, all the fish (both fish with a reread tag-code and no tag-code) were held in indoor cement tanks for two days for observation of possible mortality as a result of handling during the sampling procedures. The size of the tank was 72 m^2, and the stocking density was about 20 individuals per m^2. A few fish died during this period and the tags of these fish were recovered. The fish were subsequently restocked in a new earthen pond of 0.34 ha size with a water depth of 2.0 m. The fish were reared in the same pond until the second sampling (about six months or a year after communal rearing). Throughout the culture period, complete pellet feed (28 percent protein and 3 percent lipid) was fed twice a day (early morning and late afternoon) to the fish until satiation. The feeding rate varied between one and four percent of the body weight, adjusted according to ambient temperature. The stocking density during this rearing period was 15 000 tagged fish per ha, with an additional 2 000 silver carp per ha and 1 000 bighead carp per ha. Stocking of silver carp and bighead carp was aimed to regulate the water fertility. The water temperature during this period (January to December) ranged from 4°C to 32°C.

1.4 Harvesting

The fish were harvested yearly for measurements through total drainage of the pond because common carp is difficult to catch by netting. For each fish with an identified tag code, body weight, length and height were recorded. Approximately 0.09 percent of the total fish with a tag code could not be identified or scanned. Similarly, a second harvesting and measurement of the tagged fish was conducted after about one year of culture from first harvest (two years old). The sex of each fish with an identified tag code was also recorded in addition to body weight, body length and body height. During this period, only 0.07 percent of the total fish lost their tags or the tag codes scanned did not match with earlier records.

1.5 Selection procedures

Linear animal mixed model analyses were performed to estimate the breeding value (EBV) of individual fish. Based on the individual and family rankings by EBV, the mating protocol was carefully designed to avoid mating among close relatives. About twice the actual number of breeders was selected as candidates for the selection and control lines, and were stocked in an earthen pond under intensive care. In each generation, the mating list consisted of 90 pairs for the selection and 20 pairs for the control. The selected male and female breeders were kept in separate earthen ponds to avoid possible natural breeding. The fish were given breeder pellet feed (30 percent protein and 3 percent lipid). Good water quality was maintained during this period. Induced breeding by hormone injection was performed. A small proportion of pairs (3 percent to 10 percent) failed to spawn initially across the generations and some of these ranked at the top by EBV and therefore these were intensively cared in indoor tanks (males separated from females) to condition for a second spawning attempt. About 60 percent of these pairs successfully spawned after the second hormone intervention. High mortality occurred in some families (survival <100 fry) probably because of poor fertilized egg quality.

In total, 66 to 84 selected and 16 to 19 control families were successfully produced across the generations. Fry nursing/rearing, tagging, communal grow-out, harvest and data recording, as described above, were carried out. After the genetic evaluation, a new cycle was repeated. The same selection procedure, animal husbandry and management regimes were practiced in all the generations. After four generations of selection, an improved strain was developed and was denominated as the FFRC strain common carp, *Cyprinus carpio*.

The combined selection, which integrated family selection with quantitative genetic analysis, makes a great contribution to the genetic improvement of common carp. In the genetic improvement project (least squares means (LSMs) for body weight were obtained from a linear mixed model and a threshold generalized logistic model) the FFRC strain common carp had significantly greater body weight than that of the control in all generations ($P<0.05$ to 0.01). Direct changes in body weight to the FFRC strain increased with successive generations ranging from 3 percent to 7 percent. Genetic response to selection was measured as the difference in estimated breeding values (EBVs) between the selection line and control or between successive generations, and the FFRC strain achieved a cumulative direct genetic gain of 28 percent, averaging 7 percent per generation.

2. Process of demonstration and dissemination

2.1 On-farm testing

As the FFRC improved strain of common carp was developed in Wuxi City, Jiangsu province the performance testing for validation was done in other locations. In order to test the interactions between genotype and environments, on-farm tests and demonstration of the FFRC strain common carp were conducted in several locations of China. Dongping county of Shandon province, Pi county of Sichuan province and Tongshan county of Jiangsu province were selected as the places for on-farm testing. The growth performance between the selection line (FFRC strain) and the control line was compared in Dongping county and Pi county, the growth performance between the FFRC strain and the local common carp variety was compared in Tongshan County. In order to get objective results and remove bias at the level of farmers, label "1" and label "2" were used instead of selection line and control line in Dongping county and Pi county. During the spawning season (April), the broodstock out of the selection and control lines were selected and induced with hormone on the same day. After rearing the spawn, the fries were transported to different places with the labels on the packs in late April. In Dongping county six ponds (each pond 2 666.7 m^2) were used for the comparison of fingerling performance and fries from each of the two lines were stocked in triplicates with a stocking density of 5 000 individuals per pond. After six months of grow out, the FFRC strain grew 29.94 percent faster than the control line. In Pi county, four ponds (each pond 3 333.3 m^2) were used for the comparison of food fish culture. FFRC strain and control line fries were stocked in duplicates. Here, the stocking densities were 5 000 individuals per pond and 4 200 individuals per pond. After seven months of grow out, the FFRC strain grew 20.10 percent faster than the control line. In Tongshan county, five cages (each size 5 m $\times$ 5 m $\times$ 2.5 m) were set in the Tongshan Reservoir, with three cages for culture of FFRC strain and two for the control with a stocking density of 6 000 individuals per cage. After six months of grow out culture, the FFRC strain grew 39.19 percent faster than the control line (Table 1). The on-farm tests indicated that there was no interaction between the FFRC strain and the control line. The FFRC strain common carp was also disseminated to other places.

Table 1 Growth performance from on-farm testing experiments of the FFRC strain common carp compared with control line or local variety

Location	FFRC strain (g)	Control line or local variety (g)	Superiority (%)
Dongping county	400.80±95.86	308.44±79.08	29.94
Pi county	699.47±121.14	582.58±145.75	20.10
Tongshan county	665.70±141.90	478.26±101.86	39.19

2.2 Demonstration of high profit culture

The demonstration and dissemination of the FFRC strain of common carp was carried out through the platform of the Chinese Modern Agro-industry Technology Research System. Several experienced farmers from each demonstration county were selected as demonstration farmers to culture the FFRC common carp. The farmers adopted the same culture model and culture technique as usual but the major culture variety was changed to the FFRC strain common carp. The farmers of adjacent areas observed the demonstration result and compared the culture profits after harvest (Table 2). The good performance and high profit from the demonstration of the FFRC improved strain encouraged the farmers to consciously choose the FFRC strain and replace the old variety.

Table 2 Demonstration culture of the FFRC strain of common carp in several locations

Location	×1 000/ha	Area stocked (ha)	Size (g) [Size stocked]	Duration of grow out days	Production (kg)	Income (USD)	Input-output ratio
Dongping County Shandong Province	23	1.33	925 (2)	225	20 121	13 406	1:1.40
Kaifeng City, Henan Province	30	0.8	800 (10)	350	23 085	17 375	1:1.46
Kaiyuan City of Yunnan Province	38	6 .0	800 (6)	210	25 800	12 030	1:1.38
Kaili City of Guizhou Province	45	0.2	246 (12)	108	10 035	9 550	1:1.51

2.3 Dissemination of the FFRC strain of common carp

The demand for seed supply of the improved FFRC common carp strain from farmers increased after successful demonstration. An integrated amplification and dissemination system of the improved strain was established to produce a large quantity of high quality seed of the FFRC strain of common carp. The Experiment Station recommended a hatchery with good facilities and technical skills as the amplification base. The genetic breeding centre of FFRC provided improved common carp broodstock to the hatchery. These were from two families that have high estimated breeding value (EBV) (in the top ten) and of distant genetic relationship. The breeding plan guidelines recommended only an interfamily mating design and discouraged intrafamily mating. The two family broodstocks with high EBV ensured the good quality of offspring, and the mating between two families with distant genetic relationship safeguarded against inbreeding depression. The fries and fingerlings produced by the hatchery were then disseminated to the farmers in the local province or neighbouring provinces. At present, six key amplification bases have been established in Ningxia, Guangxi, Guizhou and Henan provinces.

3. Impact created

3.1 Good performance of the improved strain

At the farm level, the FFRC strain showed a positive impact on the production yield and profit. The FFRC strain of common carp can be cultured under various conditions such as pond, cage and paddy field. In Guizhou Province, the FFRC strain has been disseminated into ponds totalling more than 360 hectares and paddy fields totalling 667 hectares over the last three years. In pond culture, the yield increased 20.21 percent to 25.36 percent, and in paddy field culture the yield increased 85 percent to 194 percent. The FFRC strain has benefited 18 cooperatives, 16 enterprises and 3 679 farmers. The cumulative increment of profit in these three years was USD2.6 million. In Gansu province, the FFRC strain of common carp grew significantly and created new records for common carp culture. In Yongjing county, the FFRC strain can reach an average body weight of 410 g with the maximum body weight of 600 g in five months as compared to the local variety that only has an average body weight of 150 g. One third of the FFRC strain of common carp attained the size of 450 g to 600 g and could be sold to the market. In Jingyuan county, the fingerling size of the FFRC strain of common carp reached 265 g in five months. This is the first time such a large size of common carp fingerling has been recorded in this county. Besides the growth rate, the FFRC strain of common carp performed well in terms of survival rate and FCR (Table 3).

3.2 Dissemination status of the new strain

Ningxia province and Gansu province lie in the northwestern part of China and Liaoning province is located in the northeastern part of China. The temperatures in these regions range from -25°C to 35°C . Sichuan, Shandong and Henan provinces are in the central and eastern parts of China. The temperature in these areas is similar to that in Jiangsu province with the range of -10°C to 40°C. Guizhou province and Yunnan province are located in the southwest part of China, the temperature ranges from -2°C to 30°C. The demonstration and farm-testing experiments in the above regions indicated the FFRC strain of common carp performed well under various climates and could be widely disseminated to different places in China. At present, the FFRC strain of common carp has been disseminated to a total of 20 provinces, namely Jiangsu, Shandong, Henan, Jilin, Liaoning, Sichuan, Ningxia, Inner Mongolia, Shannxi, Xinjiang, Yunnan, Guizhou, Guangxi, Fujian, Gansu, Chongqing, Anhui, Guangdong, Shanxi and Tianjin. The cumulative dissemination area is 40 thousand hectares and the production value has increased more than USD80 million. More than 1 000 technicians and farmers have received training in breeding and culture techniques.

Table 3 The improved performances of the FFRC strain of common carp compared with a local variety at the farm level

Trait	Location	FFRC strain	Local variety	Superiority
Weight	Dawa county, Liaoning province	593.57±132.71 g	480.13±105.62 g	23.63%
	Suiyang county, Guizhou province	286.15±46.17 g	221.60±40.28 g	29.13%
	Yongjing county, Gansu province	1 061.1±217.38 g	789.5±186.74 g	34.40%
	Pingluo county, Ningxia province	847.53±170.39 g	665.67±140.29 g	27.39%
	Yinchuan city, Ningxia province	1 060.50±221.42 g	812.36±181.35 g	30.55%
Survival rate	Suiyang county, Guizhou province	91.9%	87.7%	4.2%
	Yongjing county, Gansu province	95.2%	94.2%	1.0%
	Yin Chuan, Ninxia province	94.7%	85.8%	8.9%
FCR	Suiyang county, Guizhou province	1.36	1.67	22.79%
	Pingluo county, Ningxia province	1.65	1.79	8.48%

4. Lessons learned

4.1 Selection response of the improved strain

In this genetic improvement project, a combined selection methodology that integrates family selection with quantitative genetic analysis was adopted. Family information was used to make a complete pedigree that can be implemented to avoid the problem of inbreeding. By quantitative genetic analysis, the estimated breeding value of each individual was calculated. The EBV is a measure of genetic superiority of an animal as compared to its contemporaries and is calculated from phenotypes of the individual and its relatives, and the pedigree data. Thus, an analysis of the genetic trend calculated using EBV provided a more accurate indication of amount of the genetic progress attained in selected populations for traits studied, as compared to using phenotypic means (Nicholas, 2009). Genetic evaluation demonstrated that the selection programme resulted in a remarkable improvement in growth performance in the FFRC strain of the common carp population. The average genetic gain was about 7 percent per generation (two years per generation). Our results are in agreement with those reported recently for common carp by Ninh *et al*. (2013) and Vandeputte *et al*. (2008) or in other aquatic animal species such as tilapia (Hamzah *et al*., 2014) and giant freshwater prawn (Hung *et al*., 2013). The magnitude of genetic gain generally depends on the statistical methods used or whether a comparison is made with a control or with wild stocks. In the present study, a separate control group of the same genetic origin as the selection line was maintained and contemporaneously produced in each generation.

4.2 Good performance of the improved strain under various conditions

The performance of the FFRC strain of common carp was tested on-farm at different geographical and climate locations, covering east China (Jiangsu and Shandong provinces), southwest China (Sichuan province and Guizhou province), northwest China (Gansu province and Ningxia province) and northeast China (Liaoning province). Compared to local common carp varieties, the FFRC strain exhibited significantly higher growth, survival and a lower food conversion rate across all the regions. The superiority of the FFRC strain of common carp under both selection and production environments demonstrates that the genetic progress achieved in the nucleus is also effectively expressed under farming conditions. Therefore, the use of the improved strain can help farmers/producers to accelerate commercial production in the country and internationally.

4.3 Demonstration and dissemination platform

The demonstration and dissemination of the FFRC strain of common carp relied on the platform of the Major Freshwater Fish Industry Research System, one of fifty Chinese Modern Agro-industry Technology Research Systems. The Major Freshwater Fish Industry Research System consists of 25 research stations and 30 experimental stations distributed throughout the country. The staff in the experimental stations have considerable knowledge of local conditions and the farmers. They can reflect the technical demands from farmers and introduce the farmers to the achievements from the research station. Through this point-to-point linkage between the research station and the experiment station, new varieties and techniques can be demonstrated and disseminated easily and rapidly.

4.4 Existing challenges

Despite the successful outcome for this selective breeding programme for common carp in the present population, there are also challenges that should be considered for the programme's long-term implementation. For instance, induced breeding at the first sexual maturation of the females did not result in a 100 percent success rate of spawning. A second injection was applied for females that failed to spawn the first time, causing a delay of one to two weeks compared with the normal reproduction period for culture production. In all generations, offspring from all the families were reared separately in hapas (net cages). Use of outdoor net cages installed in a pond for family rearing proved successful, but the growth and survival of the fish were not ideal in the early stage of growth development, i.e. lower than for those reared under normal pond conditions. The fact that the mesh of the cage was too fine affected the water exchange and supply of natural food into the cage and this had an adverse impact on the growth and survival of the fish. It is also difficult to keep a uniform culture environment for different families when they are in separate cages, and to ensure a normal rate of growth and development when there is a limitation with the physical rearing facilities. However, using individual earthen ponds for family rearing was not realistic because of the large number of families. Cages were still used for family rearing in all generations. One option to overcome these limitations is to apply DNA markers for parentage assignment to enable the early communal rearing of all families after birth as demonstrated in common carp by Ninh *et al*. (2013).

5. The way forward

For any aquaculture enterprise, body weight and survival rate are the two traits of greatest economic importance. We are thus also interested in finding if there are any changes in survival associated with the selection programme for common carp. Correlated changes in survival with selection for increased body weight are currently not available for common carp. There is a growing concern about negative changes in fitness related traits in the artificial selection programme, however, the non-significant correlated response in survival indicates that selection for high growth did not have any evident detrimental effect on this trait (Ninh *et al*., 2014). A number of studies report that index selection, combining growth and survival, resulted in simultaneous improvement in both traits in Pacific white leg shrimp *Liptopenaus vannamei* (Gitterle *et al*., 2007), tilapia

Oreochromis aureus (Thodesen *et al.*, 2013) or abalone *Haliotis diversicolor* (Liu *et al.*, 2015). Expansion of the breeding objectives for common carp by including new traits, especially survival rate or disease resistance, are also being considered in our future studies.

The heritability obtained for body weight in the FFRC strain is of moderate magnitude and this indicates that this population of common carp has the potential to show further response to selection. Our estimate of heritability for body weight is in conformity with those reported for common carp (Vandeputte *et al*., 2004; Kocour *et al*., 2007; Nielsen *et al*., 2010; Ninh *et al*., 2011) or other fishes (Hamzah *et al*., 2014) as well as for crustacean species such as shrimp (Nguyen *et al*., 2014) or mollusc, e.g. abalone (Lui *et al*., 2015). In a review of earlier studies, Vandeputte (2003) reported the heritability range for body weight from 0.00 to 0.75 for common carp. A synthesised summary of the literature results together with the heritability estimate obtained from our present study suggest that ongoing improvement of growth related traits through selective breeding should be effective as demonstrated in this population. We will record growth and survival traits during the early phase of rearing to conduct a formal genetic evaluation for these characteristics as part of the efforts to broaden the breeding objectives in the present common carp population.

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Country Paper 2: Genetic improvement and dissemination of rohu (*Labeo rohita*) in India: impact and lessons learned

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Abstract

Selective breeding is carried out to improve the growth trait genetically for one of the most preferred carp species (rohu) in India. The project on the "Selective breeding of rohu" was initiated at CIFA in collaboration with the Institute of Aquaculture Research (AKVAFORSK), Norway in 1992. Improved rohu, or "Jayanti rohu", has been developed through selective breeding following the combined selection method. To establish the base population, rohu stocks were collected from different rivers such as the Ganga, Yamuna, Gomti, Brahmaputra and Sutlej. The local CIFA farm stock was added as a sixth stock to these base populations. After eight generations of selection, 18 percent higher growth realization per generation has been achieved. The field testing of Jayanti rohu was carried out in the states of Odisha, West Bengal, Andhra Pradesh and Punjab and yielded encouraging results. Disease resistance against *A. hydrophila* was added as a second trait of selection to the ongoing rohu breeding programme. After mass challenge tests, two lines of rohu have been produced, i.e. a resistant line and a susceptible line. The resistant line rohu showed significantly higher survival compared to the susceptible line. Disease resistant rohu is under field trial at present. The encouraging results with rohu have paved the way for initiation of selective breeding programmes in other species.

Jayanti rohu has been disseminated to different states of India with a high acceptance rate by fish farmers and hatchery owners. In India, 16 states have already received Jayanti rohu from the nucleus, i.e. CIFA, as well as different multiplier units. The improved rohu also proved to be feed neutral and effective under all the normal culture practices and this has enhanced the acceptance rate. An impact assessment study further confirmed the superiority of the Jayanti strain of rohu over the normal rohu.

Introduction

Freshwater aquaculture is one of the fastest growing subsectors in India and has registered a 5.1 percent annual increase in the last 60 years. The projected fish production in the country is estimated as 17.5 million metric tonnes (MMT) for the year 2050 with aquaculture likely to contribute 13.3 MMT. Therefore, the aquaculture production needs to be increased from the present level of 5.1 MMT to 13.3 MMT, which is a 2.5 times (approximately) increase over the present production level.

Carp, being the mainstay of Indian aquaculture, has received keen attention from researchers in the country over the last five decades. The three Indian major carp (IMC) species *viz*., catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) are cultivated all over the country. The exotic carps, namely silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*), which were introduced during the seventies, form the next important group for aquaculture. Mostly the IMCs are cultured alone or along with the exotic species under composite fish culture and together contribute more than 82 percent of the total culture production of the country. After the success of induced breeding technology, a large number of hatcheries have been established in the country. Today, the country is self-sufficient in the production of carp seed through a network of more than 1 700 freshwater carp hatcheries established in the country by both private and public participation. However, much less importance is being given to the quality of carp seed and this has resulted in the problem of inbreeding in many hatcheries.

Selective breeding work was initiated at the Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, India in collaboration with the Institute of Aquaculture Research (AKVAFORSK), Norway to improve the growth in rohu genetically. The main objectives of the selective breeding of rohu programme were to obtain information about the magnitude of the genetic variation for growth and survival in rohu and to develop a breeding programme of rohu based on the result obtained at the centre as well as at different field trial units.

Rohu (*Labeo rohita*) is one of the most preferred species by Indian consumers. However, its growth performance is slower when compared to other species in the multispecies culture system. Rohu is also more susceptible to different diseases. Taking all these factors into consideration, rohu was selected as the species for genetic improvement through selective breeding, particularly for the growth trait. Later on another trait, i.e. disease resistance against *A. hydrophila*, was added to the breeding programme.

1. Selective breeding of rohu

1.1 Establishment of base population

Founder populations of *Labeo rohita* have been collected from five different rivers in North India, namely, the Ganga, Gomti, Yamuna, Sutlej and Brahmaputra rivers, which are the native habitat of rohu. Rohu stock from the fish farm of CIFA (local) has also been added to the gene pool. Here, the Ganga, Gomti and Yamuna rivers are part of the Ganga river basin, Sutlej is part of the west flowing Indus basin and the Brahmaputra is a separate basin but joins with the Ganga river in Bangladesh. Thus the base population for the selection project consisted of rohu from the six stocks. The fry or fingerlings collected and brought to CIFA were quarantined for about two weeks in cement cisterns. After quarantine, fingerlings were marked by fin clipping, M-procaine blue dye marking or by a combination of both. They were stocked in communal ponds for rearing until they reached sexual maturity. During the first year, only the Ganga river and local hatchery stocks were used and subsequently during 1994, the stocks from the other four rivers were added to the breeding programme. Genetic characterization of the six base population stocks indicated a significant variation within each stock. The variation within stocks was greater than that observed between stocks (Reddy *et al.*, 2002). In order to estimate the magnitude of heterosis for harvest body weight, two 3×3 diallel crosses were made (Gjerde *et al.,* 2002). Rohu stocks included for two diallel crosses are presented in Table 1. However, negative to very low heterosis effect on growth was observed. Therefore, pure breeding was considered as the selection method for genetic improvement of rohu.

Table 1 Rohu stocks included for two diallel crosses

Female Male Sire strain	Ganga	Yamuna	Local	Brahmaputra	Sutlej
Ganga	×	×	×		
Yamuna	×	×	×		
Local	×	×	×	×	×
Brahmaputra			×	×	×
Sutlej			×	×	×

1.2 Brooder raising and breeding strategies

The fingerings collected from different localities were raised to maturity in triplicate communal ponds on the CIFA farm. The broodstock was induced bred using synthetic GnRH hormone analogue (Ovaprim/Ovatide) for ovulation of females and sperm collection (milting) from males. Full-sib families were produced using nested mating design (two males nested within a female or vice versa). To date, 21-year classes of full-sib and half-sib families have been produced with nine complete generations. Approximately 60 full-sib families were produced in each year class.

The eggs from different families were incubated separately. One specialized hatchery (Figure 1) was constructed for incubation of eggs separately and for full-sib family production. For spawning purpose, a circular eco-carp hatchery was used. However, for separate family-wise production of hatchlings, acrylic jars were used. Hatchlings were also collected in hapas separately and reared for 60 to 72 hours before being released in the nursery ponds.

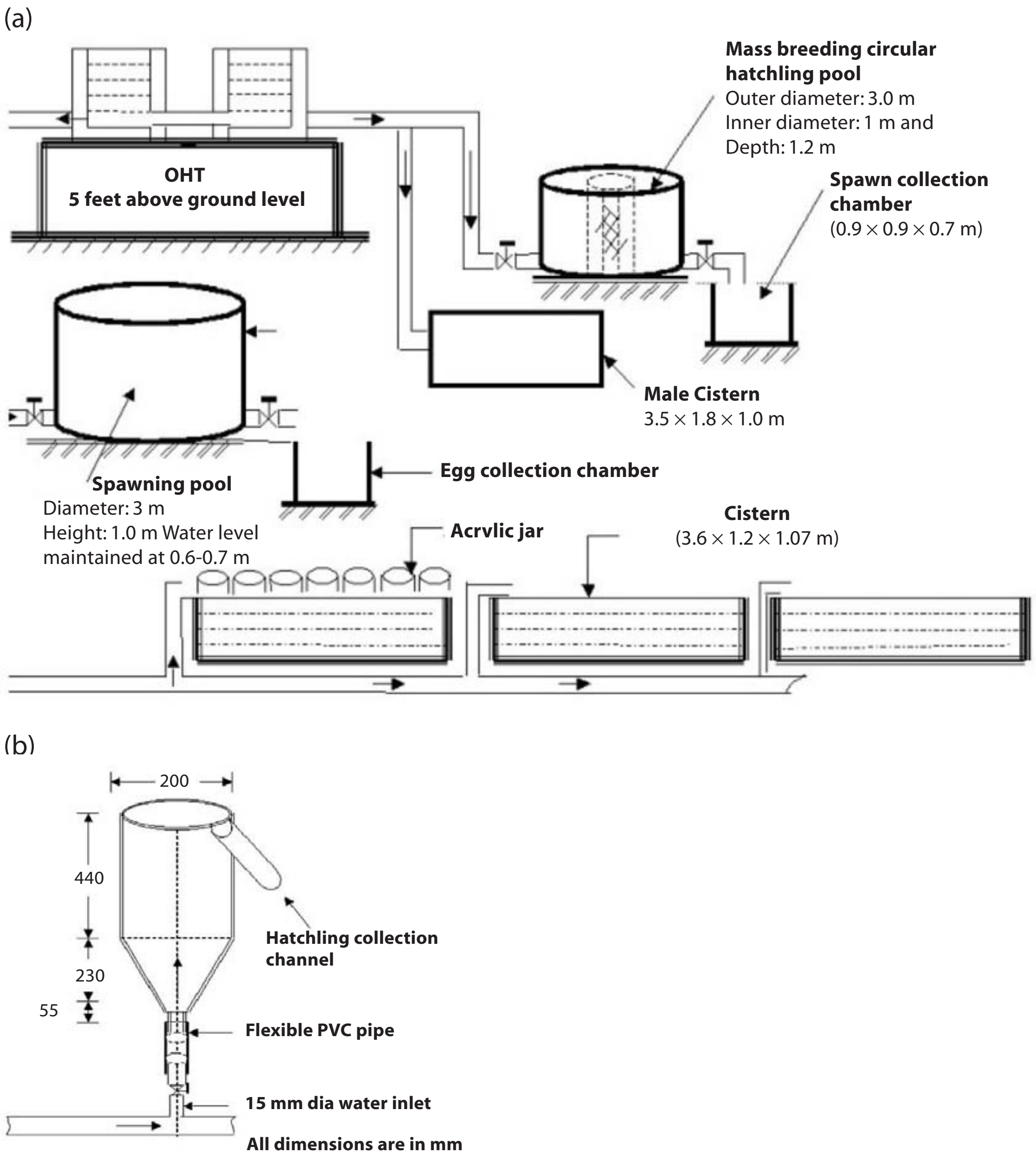

Figure 1 Prototype selective breeding hatchery (a) Layout diagram of specialized selective carp breeding hatchery (b) View of single unit acrylic jar

1.3 Nursery rearing

After 72 hours of incubation in the hatchery, spawn from different full-sib families were stocked in 100 m^2 nursery ponds (Figure 2). Spawn were reared to taggable size fingerlings (8 g to 10 g) in nursery ponds. Nurseries were prepared before release of spawn following standard recommended methods. This ensured a rich plankton source during the rearing phase. In addition to natural food, supplementary feeding was done at the rate of double the weight of spawn during the first five days, three times from the sixth to the tenth day and four times from the eleventh day till taggable size was reached.

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Figure 2 Partitioned nursery ponds for full-sib family rearing

1.4 Tagging

Rohu is one of the most active swimmers, so retention of external tags was extremely poor. Moreover, external tagging very often put them at risk of secondary infection. An internal tagging system using Passive Integrated Transponder (PIT) tags was suitable and effective. After the fish attained suitable tagging size (8 g to 10 g), they were tagged with PIT tags. Thereafter, tagged fingerlings were stocked in ponds for communal rearing under both monoculture and polyculture systems (Das Mahapatra *et al.,* 2001).

1.5 Communal pond rearing

Tagged fingerlings were stocked in the well-prepared ponds in triplicates. Rearing was initially done in monoculture and polyculture systems. In polyculture ponds, rohu was stocked along with catla and mrigal. After a period of one year, data pertaining to growth (length and weight) was recorded and analyzed to evaluate the individual breeding value and to rank the fishes. Base population data indicated that growth and survival of the wild rohu stocks were equal to or better than the farmed stock. A substantial additive genetic variation has been observed for growth rate and survival of rohu, both under monoculture and polyculture systems, thus indicating that growth rate and survival of rohu can be improved through selective breeding. However, competition for food may prohibit rohu from exhibiting its growth potential in polyculture. Proper feeding and pond management is essential when testing fish in a breeding programme. This preliminary observation strengthened the ongoing selective breeding programme and provided proper direction to it.

The study also indicated that stocks and full-sib groups within stocks ranked consistently high for growth performance in monoculture and polyculture systems, which suggested that there is no need for the development of special rohu lines for different systems of culture.

1.6 Feed and feeding requirement in grow out rearing

During the grow-out period, fishes were fed at 3 percent to 4 percent of body weight per day given in two installments (see Table 2 for feed composition). Health monitoring was done by periodical checking of stocked fishes and by giving appropriate treatment whenever necessary. However, other traditional feed such as groundnut oil cake and polished rice at 1:1 ratio was also used in many of the farmers' ponds and the good response by the improved rohu indicated feed neutrality of the improved stock.

Table 2 Feed ingredients and composition for growout culture

	Feed ingredient	Composition (%)
1	GOC	40
2	Soyabean meal	20
3	Polished rice	25
4	Fishmeal	12
5	Vegetable oil	1
6	Vitamin mineral mix	2
	Total	100

1.7 Statistical analysis

Editing of the data and basic statistical analysis were carried out using SAS 9.1 and 9.2 (SAS Institute Inc.). For each year class, breeding values for the harvest body weight (for the trait selected in each year class) were calculated for all breeding candidates (using own, full- and half-sib body weight records) using an SAS programme developed in the project for the analysis. In the rohu breeding programme a selection index procedure has been used to estimate breeding values. Information from full-sibs, half-sibs and individuals are being considered for breeding value estimation. This procedure efficiently combined all the available information about single as well as multiple traits recorded for the breeding candidate and its relatives into an index of genetic merit. Fish with an average breeding value were chosen as controls and in every generation they were compared with the selected (higher breeding value) individuals.

1.8 Estimation of genetic parameters

In the rohu breeding programme, total heterosis for each of the six base population crosses was low or negative, whereas average heterosis was low and mostly not significantly different from zero ($P>0.05$). Therefore, it was concluded that genetic improvement of rohu by crossbreeding would be futile (Gjerde *et al*., 2002). At tagging, the heritability (h^2) for body weight was low whereas the environmental effect common to full-sib families other than additive genetics was high. For sampling and final sampling the heritability was moderate (0.23±0.08). The phenotypic and genetic correlations between sampling and final sampling weights were 0.92 (±0.01) and 0.98 (±0.01) respectively, indicating that they were virtually the same trait.

1.9 Realized selection response

In each generation a control group was created by mating average ranked individuals. The progeny of these was compared with that of offspring from selected parents of the selection line. One of the main objectives in a breeding programme is to maximize the genetic gain per generation of selection. This is obtained by selecting individuals with relatively higher genetic merit or breeding value. In the rohu breeding programme avarage genetic gain of 18 percent per generation was observed after eight generations of selection in the research centre. However, a much higher response was observed in different field testing centres.

2. Field testing

To evaluate growth performance of improved rohu in different geographical regions of India, multilocational field trails were conducted at (1) Rahara, West Bengal (Eastern India), (2) Ludhiana, Punjab (Northern India), (3) Vijayawada, Andhra Pradesh (South-Central India, and (4) State Fisheries Department, Odisha (Eastern India) during 1999 to 2001. During 2005 and 2006 demonstrations were also arranged at farmers' ponds in different states of India. Performance evaluation of improved Jayanti rohu in comparison to local rohu and with the control group from the research centre, was carried out. In the field trails at all these places, improved Jayanti rohu showed significantly higher growth efficiency over the local and control rohu. A growth rate superiority of up to 75 percent was observed for improved Jayanti rohu over local rohu under field testing.

2.1 On-farm field evaluation of improved rohu

Under a collaborative programme of CIFA with the WorldFish Center, Penang Malaysia, field evaluation in farmers' fields at Odisha and West Bengal was conducted to evaluate growth potential of improved Jayanti rohu. On-farm field trials at all the four places of Odisha showed significantly higher growth of Jayanti rohu over local rohu (Table 3). In farmers' fields the evaluation of the fifth generation of improved rohu showed 98 percent to 126 percent higher growth rate than the local rohu. In some places Jayanti rohu also showed higher growth efficiency than *Catla*, which generally grows much faster than normal rohu.

Table 3 Overview of on-farm field trails in Odisha: Jayanti rohu (JR) and local rohu (LR)

Place	Year	No. of ponds	Stocking combination	% of higher gain of JR over LR	% of higher gain of JR over Catla
Alisisasan	2005	2	JR + LR + Catla	P1 - 98 P2 - 120	18
Bhadrak	2005	2	P1 - LR + Catla; P2 - JR + Catla	117	20
Kendrapada	2005	2	P1 - LR + Catla; P2 - JR + Catla	100	–
Keonjhar	2006	84	JR + Catla + Mrigal; LR + Catla + Mrigal	128	56

In West Bengal, Jayanti rohu seed was obtained from the multiplier unit, Rahara, which belonged to third generation seed. On-farm field trial was conducted in four ponds (0.08 ha to 0.33 ha). Absolute growth increment was observed to be significantly high for Jayanti rohu. Average growth was 1.48 g/day ranging from 0.79 g/day to 2.01 g/day against an average of 1.22 g/day for the local rohu ranging from 0.51 g/day to 1.71 g/day. Growth of *Catla* was observed to be high except in pond no. 4 (see Table 4).

Table 4 Absolute growth increment/day (g) of fishes considering total culture period

Pond	Catla	Jayanti rohu	Local rohu	Mrigal
P1	3.18	2.01	1.66	1.74
P2	1.64	1.30	0.99	1.01
P3	1.59	0.79	0.51	0.64
P4	1.07	1.82	1.71	1.74

2.2 Cryopreservation of improved rohu milt

Milt (semen) samples from Jayanti rohu (20 families per year for three years) were collected and analyzed for quality assessment and cryopreservation. The semen analysis showed a spermatocrit value in the range of 49 percent to 62 percent with a sperm count range of $1.8–2.0 \times 10^7$ to $2.8–3.0 \times 10^7$cells per ml. Milt cryopreserved with higher amount of D-Glucose (10 mg/100 ml extender) showed better post thawing motility and significant fertilization efficiency. A comparable fertilization of more than 73 percent was obtained using cryopreserved milt (80 percent in control). However, the fertilization rate also varied widely between families. It may be concluded that the cryopreserved milt of different families of rohu can be utilized for seed production and for dissemination.

3 Dissemination of improved rohu

The improved rohu, which was named Jayanti rohu in 1997 (which was the 50th anniversary of Indian independence referred to in Hindi as *Swarna Jayanti*), has been released to several hatchery owners so that they can provide better quality seed to the fish farmers. The dissemination strategies (Figure 3) for improvement primarily aimed at the following:

- maintenance of a genetically improved strain;
- dissemination to a larger domain of fish farmers;
- protection of the interests of small and marginal farmers;
- large scale availability of seed at a reasonable price; and
- capacity building of seed producers.

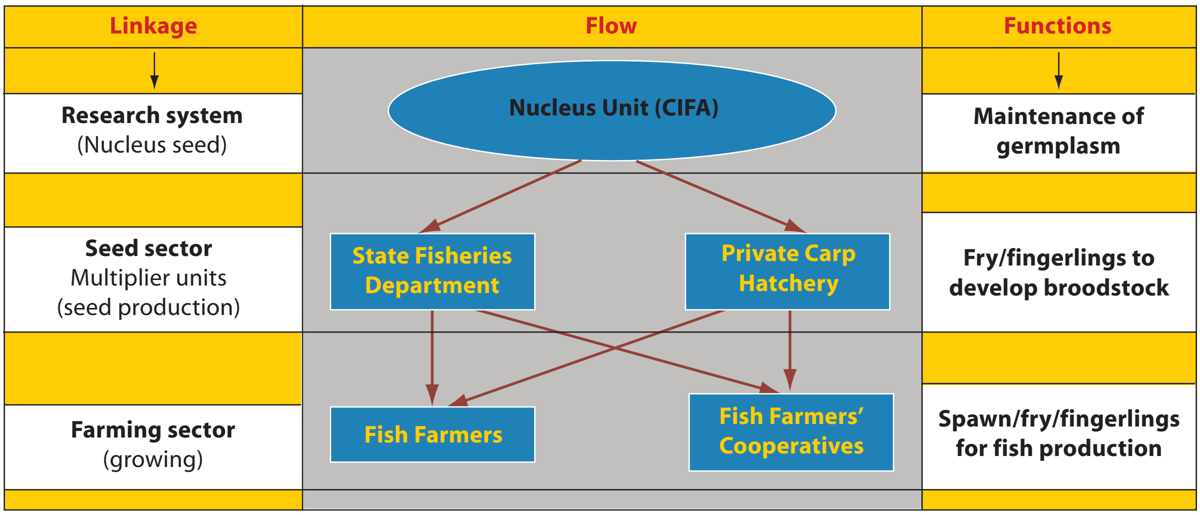

Figure 3 Dissemination plan for Jayanti rohu

Initially, the dissemination of improved rohu was carried out in three states, namely Andhra Pradesh, Orissa and West Bengal. It is now being disseminated to other states in India. CIFA, the research centre, is where the nucleus resides, and provides improved rohu seed to the multiplier units. Multiplier units are raising the brood fishes, producing seed and distributing the seed to the fish farmers.

In order to capitalize on the efforts made for the development of Jayanti rohu, efforts have been made to disseminate to farmers through private and public hatcheries with close monitoring by the institute. At present, improved rohu seed has been disseminated to 16 states in India and more than ten million seeds are disseminated every year from CIFA itself (see Table 5 for dissemination figures from 2009 to 2015). CIFA is also supporting the State Government's National Freshwater Fish Brood Bank at Kausalyaganga in its brood stock upgradation programmes.

Table 5 Production and dissemination of improved rohu from CIFA (in millions)

Achievements	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
Total spawn production	15.725	8.225	12.30	29.375	26.515	33.475
Dissemination of improved rohu seed	14.725	8.225	10.60	27.275	21.315	29.95
CIFA own farm stocking	1.00	1.70	1.70	2.10	5.20	3.525

3.1 Activities and technical programme of nucleus/apex body

As all the facilities are available at CIFA, it is acting as the nucleus or apex body for the dissemination. It is also the responsibility of CIFA to supply the improved rohu seed to the multiplier units from time to time. CIFA is responsible for fixing the price guideline for improved rohu taking into consideration small and marginal farmers. CIFA is also providing feeding and other husbandry practices for improved rohu culture.

4 Selective breeding of rohu for disease resistance against A. hydrophila

In addition to growth, disease resistance against *A. hydrophila* was also included in the rohu breeding programme from the year 2004. A reliable challenge test has been developed against aeromoniasis after collecting the bacterial isolates from different regions of India and testing their pathogenicity through a series of challenge tests. Ten different pathogenic isolates of *A. hydrophila* were collected from different regions of India. One of these isolates (Ah #4) was found most virulent and suitable based on pathogenicity, and thus selected for all the further challenge tests.

Fish from as many as 40, 47 and 51 full-sib families from 2003, 2004 and 2005 year classes, respectively, were challenged with *A. hydrophila* at 5×10^6 CFU/g fish along with the control families from respective year classes. All challenge tests were performed in duplicate. A wide variation in percent survival among the families was observed in all the three-year classes. The ranges of percent survival were 17.39 to 75, 33.33 to 90 and 20 to 70.37 for 2003, 2004 and 2005 year classes, respectively. Coding of dead and surviving animals was done as 0 and 1, respectively. Apart from that, time intervals for mortality were also recorded during the experiments. Hourly mortality recorded during the challenge tests showed that most of the fish died within 24 hours of challenge. The fish were observed for a period of 30 days for mortality. The cause of mortality was confirmed by re-isolating bacteria from the kidneys of 10 percent of the dead fish.

Based on the results of a binary threshold model analysis, the heritability (±SE) for survival in the controlled challenge test was estimated to be 0.11±0.04, indicating low but significant additive genetic variability (Das Mahapatra *et al.,* 2008). These results were further substantiated by the considerable difference in mean survival between offspring produced from HR (high resistance) and LR (low resistance) breeders in the divergent selection experiment, which clearly suggested that significant genetic improvement is possible for innate resistance to aeromoniasis in rohu carp through systematic selection. Variation in innate immune response in different families was also studied. A wide range of variation was observed in different immune parameters under different year classes. During the year 2006, offspring were produced from susceptible and resistant families. Two extreme lines (resistant and susceptible) were produced. The offspring of both lines were challenged and the realized response to selection was found to be 31.1 percent in the first generation and 58 percent in the second generation.

During 2009, another mass challenge test was carried out on 52 full-sib families and a control group against aeromoniasis and correlation with growth was determined. The following observations are made:

- there is substantial variation between families with respect to survival in challenge testing with *A. hydrophila*;
- based on sire-dam models, the underlying heritability of survival at the end of the test was 0.15-0.19;
- longitudinal survival analysis (survival score models) provided better predictive ability compared with cross-sectional models (dead/live), particularly for threshold models (up to 8 percent increase in accuracy of breeding values);
- time until death and final survival were essentially the same trait (correlation = 0.97);
- survival was favourably correlated (0.43) with growth; and
- over 26 000 putative SNPs and 1 700 microsatellite loci were detected in the mRNA-seq generated from both the lines (resistant and susceptible) of rohu. Quantitative trait locuses (QTLs) associated with *A. hydrophila* resistance were identified. Serum ceruloplasmin could serve as an indirect marker for selection.

5. Impact assessment of improved Jayanti rohu

In collaboration with the Worldfish Center, Malaysia a project on impact assessment was carried out by CIFA and the Central Inland Fishery Research Institute (CIFRI), Barrackpore, India. Impact assessment was made in three modes i.e. ex-ante analysis, monitoring and evaluation and ex-post analysis. The ex-ante analysis was done before the technology was disseminated to generate potential impact. Monitoring and evaluation were done during dissemination and adoption to provide the feedback and responses by the users. The ex-post analysis was made after the technology was widely used and adopted in the field. Real farmers' data, mostly from Andhra Pradesh, were used in the study. Second or third generation seed of improved rohu was distributed to the fish farmers for field evaluation.

The comparative assessment of Jayanti and non-Jayanti growers among the farmers of Andhra Pradesh indicated lower stocking density (8.2 percent) of Jayanti compared to non-Jayanti. Application of feed per kg fish in Jayanti was found to be significantly lower (24 percent) than non-Jayanti rohu indicating the feed efficiency of improved rohu. The cost of production was reduced by Rs.6.3 per kg (26.6 percent) with Jayanti rohu with a 23 percent increase in yield. The farmers were able to shorten the crop period for harvest by almost two months (53 days) and this was a boon to farmers as they were able to avoid the water scarcity period. All the indicators pointed towards enhancement of technical and economic efficiency of the new technology (Dey *et al.*, 2013).

The internal rate of return to the investment was calculated at various stages of the adoption i.e. 10 percent, 25 percent and 50 percent. The net benefit is expected to be INR650 million (~USD10 million), INR3 310 million (~USD55 million) and INR4 710 million (~USD78.5 million) respectively. The corresponding cost-benefit ratio was found to be 13.5, 62.3 and 88.7 respectively. In other words, even with a very low level of adoption, i.e. 10 percent, the Jayanti programme is worth more than 12 times the invested cost.

5.1 Evaluation of Jayanti rohu in different states of India

A systematic study was performed by NGO, Kalong Kapili, Assam State (northeast India) by comparing improved Jayanti rohu (sixth generation) with local rohu in similar culture conditions. The average growth of improved rohu was 1.2 kg in a year as compared to normal rohu of 0.65 kg. In the same state, TATA Amalgamated (PVT) Ltd. has been culturing improved rohu for approximately six years or more and acting as a multiplier unit supplying seed to different parts of Assam and other northeastern states. The company has been successful in establishing the brand name as a supplier of quality seed because of Jayanti rohu. In the state of Bihar, Jayanti rohu dissemination started three years ago and farmers have created small hubs for dissemination of fingerlings to other fish farmers at fingerling stage. They collect Jayanti rohu at spawn stage from the nucleus and rear them for fingerlings. Because of the high growth potential and local demand they are getting a minimum of 50 percent profit and the demand is increasing every year. The situation in the state of West Bengal is similar. There is a strong demand from almost all states in India and CIFA and the national brood bank is managing to meet it.

5.2 Economic importance for the poor

The cost of production for this species is not very high since it does not require high protein feed and can be farmed with locally made plant based feed with 25 percent protein level. The ultimate target groups of this project are principally farmers and small householders, but a wide range of beneficiaries is expected including scientists, aquaculturists and commercial producers. The partner institutions involved have also gained experience in the development of breeding programmes for genetic improvement of economically important traits and other aspects of modern quantitative genetics. In this way, CIFA is disseminating directly to household farmers or indirectly through public and private hatcheries. Commercial producers or small-scale farmers are also able to access and benefit from improved seed. Consequently, it is expected to have positive social and economic impacts on the community, improving the living standard of poor people and contributing to gender equality via creation of employment for women (e.g. forward and backward linkages in seed, feed and post-harvest product) in rural areas where a large proportion of women are involved with backyard aquaculture.

5.3 Environmental impact

It is an established fact that carp culture is the foundation of sustainable aquaculture in India/Asia and thus is expected to benefit the natural environment in several ways. These carp species are farmed in inland waters so they neither compete with coastal resources nor harm coastal ecosystems. Utilization of natural feed in all the niches of waterbodies provides flexibility in the feed utilization. No genetically modified organism is used in this process so any undesirable repercussions on the environment or on the biodiversity of the aquatic system can be completely ruled out.

5.4 Constraints in rohu breeding programme

- Full-sib family production ~60 is the maximum number because of limitations in rearing facilities, i.e. nursery ponds. Rohu did not attain taggable size in smaller tanks so nursery ponds are used for rearing;
- Inbreeding accumulation because of the limited number of full-sib families every generation;
- Environment influence appeared in the nursery ponds as initial size variation observed;
- Problem during dissemination, i.e. no proper protection of Jayanti rohu as a seed certification mechanism is not functional in India; and
- False claim of Jayanti rohu for normal rohu as not distinctly different morphologically. Farmers mixed normal rohu with Jayantirohu and sold them to other farmers as Jayanti rohu. This has created problems in terms of its performance.

6. The way forward

6.1 Lessons learned in rohu breeding programme

- As it was the first ever selective breeding of any Indian major carp, many procedures and techniques for successful implementation of the programme were standardized, i.e. production of full-sib groups, establishment of model hatchery for selective breeding of carps, rearing of full-sib groups in partitioned nursery ponds, individual tagging with PIT tag, communal rearing, sampling, data analysis, estimation of breeding value and ranking of individuals in different year classes, field testing and dissemination of improved rohu;
- The experiences in the rohu breeding programme confirmed that the base population is very important as genetic variability is very essential to start any genetic improvement programme. To establish a synthetic base population within and between stock variations is essential. Molecular characterization can be added to evaluate stock variation;
- Specialized hatchery is essential for selective breeding of any carps as many field hazards can be overruled by the hatchery;
- The Passive Integrated Transponder (PIT) tag proved to be the most reliable tag for carp individual identification. The tags can be reused to reduce the cost;
- Effective dissemination mechanism is essential so that research products will reach the ultimate users. Multiplier units/hatchery managers should maintain the purity of the improved stock as mixing with local stock gives a bad name to the product. The same thing was also experienced in the rohu breeding programme; and
- Finally, project staff should be trained in quantitative genetics (if they don't alredy have knowledge of this) to understand the data analysis and interpretation. Project staff also should be well versed with the breeding protocol of the targeted fish species.

6.2 Future thrust

The Indian Council of Agriculture Research (ICAR) as well as National Fishery Development Board (NFDB), India are supporting CIFA'S continuation of the selective breeding programme of rohu. Different states are also showing interest in becoming multiplier units. By 2025 it is estimated that ~30 percent of the local rohu will be replaced by improved rohu to increase the production level in India.

Selective breeding is one of the finest tools to improve the genetic status of fish. However, it should be remembered that genetically improved varieties, whether plant, animal or fish, require specific husbandry and management practices to get the full benefit of its extra performance and Jayanti rohu is no exception to this. To realize its performance at the optimum level, management practices such as proper stocking density, balance feed and health management are essential.

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Country Paper 3: Development and dissemination of specific pathogen-free seed of *Penaeus monodon* in Thailand

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Abstract

The selective breeding programme for specific pathogen-free (SPF) black tiger shrimp *Penaeus monodon* in Thailand was launched in 2005 by National Center for Genetic Engineering and Biotechnology (BIOTEC), which is an organization under the umbrella of the National Science and Technology Development Agency (NSTDA), Ministry of Science and Industry. This programme aims to produce fast-growing and disease-resistant SPF *P. monodon* seed for farmers. The site of seed production is located in the Shrimp Genetic Improvement Center (SGIC) in Surat Thani province and this serves as the nucleus breeding centre (NBC). The shrimp stock has been screened and found free from nine viruses, two types of protozoa and one bacterium, including White-spot Syndrome Virus (WSSV) and Yellow-head Virus, and bacteria causing acute hepatopancreatic necrosis disease (especially *Vibrio parahaemolyticus*). The screening of pathogens and identification of the shrimps' genetic backgrounds are carried out in quarantine and this provides the NBC with SPF postlarvae. By means of family and mass selections in the NBC, the shrimp growth rate has been improving in every succeeding generation, and families with relative resistance against WSSV have been identified. From the sixth generation of the broodstock onward, the seed has been disseminated to farmers. This is accomplished through setting-up of a commercial broodstock multiplication centre (BMC) of SPF *P. monodon* broodstock under the support of the National Center for Genetic Engineering and Biotechnology (BIOTEC). A commercial hatchery was also set up to produce the high-quality SPF seed. Growout farms stocking the shrimp seed have had both failures and successes. Crop failure mostly happened because of mass mortality from acute hepatopancreatic necrosis disease and, to a lesser extent, White Spot Disease (WSD). In the successful crop, growth rate and survival of the shrimp grown from the SPF seeds were satisfactory. Most successful farms employ certain culture technologies to prevent the diseases, especially biosecurity, biofloc technology and co-culture with tilapia.

Introduction

Shrimp farming in Thailand began in the 1920s as an extensive-type culture (Hossain and Lin, 2001). The culture technology was simple: allowing seawater carrying aquatic animals, including natural shrimp seed, to flow into a lowland area retained by closing the outflow gate, thereafter applying tea seeds cake to kill as many fish as possible in the pond to minimize the number of shrimp predators. After five to eight months the majority of shrimp species harvested from this type of culture comprised *Fenneropenaeus merguiensis* and *Metapenaeus* spp. However, because of low production, (about 1 ton/ha), the produce of such farming was mainly used for domestic consumption.

In the 1980s, when intensive culture of the black tiger shrimp *Penaeus monodon* in Taiwan was on the brink of collapse, Thailand began to embrace technology from Taiwan. The term "intensive culture" generally means stocking density of the seed of >25 individuals/m^2, and therefore requires aeration to ensure adequate dissolved oxygen level (>4 ppm at all times). With that high stocking density, the water quality needs close monitoring (total ammonia nitrogen, <0.5 ppm; total nitrite, <0.5 ppm; pH, 8.0-8.5; alkalinity, 120 to 180 ppm), and liming was frequently employed. The production was generally 6 tonnes/ha to 10 tonnes/ha, and during the 15-year period after the beginning of the intensive farming, farmed *P. monodon* had become an important export commodity of Thailand.

As time passed, the number of shrimp farms increased, and at the same time a higher stocking density (60 to 100 individuals/m^2) became the norm. This uncontrolled progression of shrimp farming, without adequate progress in research and knowledge-based applications, harmed both the environment (Huitrica *et al*., 2002) and production. The production was affected because of an increase in the incidence of disease outbreaks, starting in the 1990s, with yellow-head disease, followed by White Spot Disease (WSD) (Wongteerasupaya *et al*., 1995a and 1995b) thus causing mass mortality of the shrimp. Several other types of viruses, bacteria, fungi and other pathogens that cause mortality or morbidity have been discovered (Flegel, 2006). The problems necessitated preventive, science-based measures in shrimp farming. The production of specific pathogen-free (SPF) *P. monodon* seed was one of such measures that allowed the provision of seed that is free from sub-clinical WSSV infections, a major factor causing WSD outbreaks in grow-out ponds (Withyachumnarnkul, 1999 and 2003). The production of the SPF seed was complemented with a selective breeding programme to improve growth rate and disease resistance (Withyachumanrnkul *et al*., 1998 and 2001). Since the breeding programme requires several generations of shrimp (roughly one year per generation for *P. monodon*) to establish, the SPF seed was not available to shrimp farmers until several years after its initial production.

Despite the on-and-off disease outbreaks, the production of *P. monodon* was increasing and had made Thailand the world's top shrimp exporting country for several consecutive years and farm shrimp production reached >100 000 tonnes per year during 2010. In late 2010, in addition to WSD, Thai shrimp farmers faced a problem of Monodon Slow Growth Syndrome (MSGS), which was later found to be associated with an infection by a newly discovered virus named Laem Singh Virus (LSNV) (Withyachumnarnkul *et al*., 2004; Sritunyalucksana *et al*., 2006). With that, the shrimp farming industry in Thailand moved from *P. monodon* to Pacific whiteleg shrimp (*Litopenaeus vannamei*) culture. The switch was for several reasons, but probably the main reason was a higher production (up to 5 to 10 times) from *L. vannamei* per unit culture area than would be achieved from *P. monodon* culture. This is because *L. vannamei* live and grow in all levels of the water column whereas *P. monodon* mainly occupies the pond bottom. Thailand had *L. vannamei* production for seven years (>500 000 tonnes/year), with intensive and super-intensive farming (stocking >150 individuals/m^3), and this shift of preferred species for culture reduced *P. monodon* production to <5 percent of the total farmed shrimp production. Among the factors that made *L. vannamei* culture more successful than *P. monodon* was its SPF status and selective breeding programme. *L. vannamei* could attain its marketable size of 12 g to 15 g within three months compared to four to five months required for *P. monodon* (for 20 g to 40 g size), thus reducing the risk of losses because of infectious outbreaks. Both shrimp species, however, are equally susceptible to most of the shrimp pathogens.

The shrimp culture industry in Thailand took another turn when a new disease, Acute Hepatopancreatic Necrosis Disease (AHPND) occurred in 2013, following the outbreaks in China, Viet Nam and Malaysia (FAO, 2003). This disease is caused by the destruction of hepatopancreas of the shrimp by plasmid-induced toxins released from the bacteria *Vibrio parahaemolyticus*, and possibly by other types of bacteria as well (Tran *et al*., 2013; Joshi *et al*., 2014). In 2014, shrimp production in Thailand dropped to 40 percent of its maximum production. Some farmers in Thailand switched back to *P. monodon* culture, although this shrimp species is also susceptible to AHPND.

During the receding period of shrimp culture in Thailand, it may be a good opportunity to promote a more sustainable shrimp culture in the country by expanding the use of SPF and selectively bred *P. monodon* combined with biosecurity measures in both hatcheries and grow-out farms. This article reports how these changes are taking place in Thailand and how they will make shrimp culture in this country more sustainable and environment friendly and at the same time help the country to move toward a more mature state of shrimp production.

1. Development and production of specific pathogen-free *Penaeus monodon*

The Government of Thailand has launched two independent breeding programmes for *P. monodon* since 2008: one carried out by the Department of Fisheries, Ministry of Agriculture and the other by the National Center for Genetic Engineering and Biotechnology (BIOTEC), an organization under the National Science and Technology Development Agency (NSTDA), Ministry of Science and Industry. Similar programmes have also been carried out by some private sectors in the country. The breeding programme set up by BIOTEC has three separate units, the quarantine, the nucleus breeding centre (NBC) and the broodstock multiplication centre (BMC) that operate in a sequence. Under this set up, Walailuk University in Nakon Si Thammarat province functions as the quarantine, the Shrimp Genetic Improvement Center (SGIC) located in Surat Thani province serves as the NBC, and Burapa University in Chanthaburi province is the BMC. To address biosecurity concerns, the three units are geographically separated (Figure 1). The aim of this breeding programme is to produce SPF *P. monodon* broodstock and seed with improved growth rate and disease resistance for aquaculture.

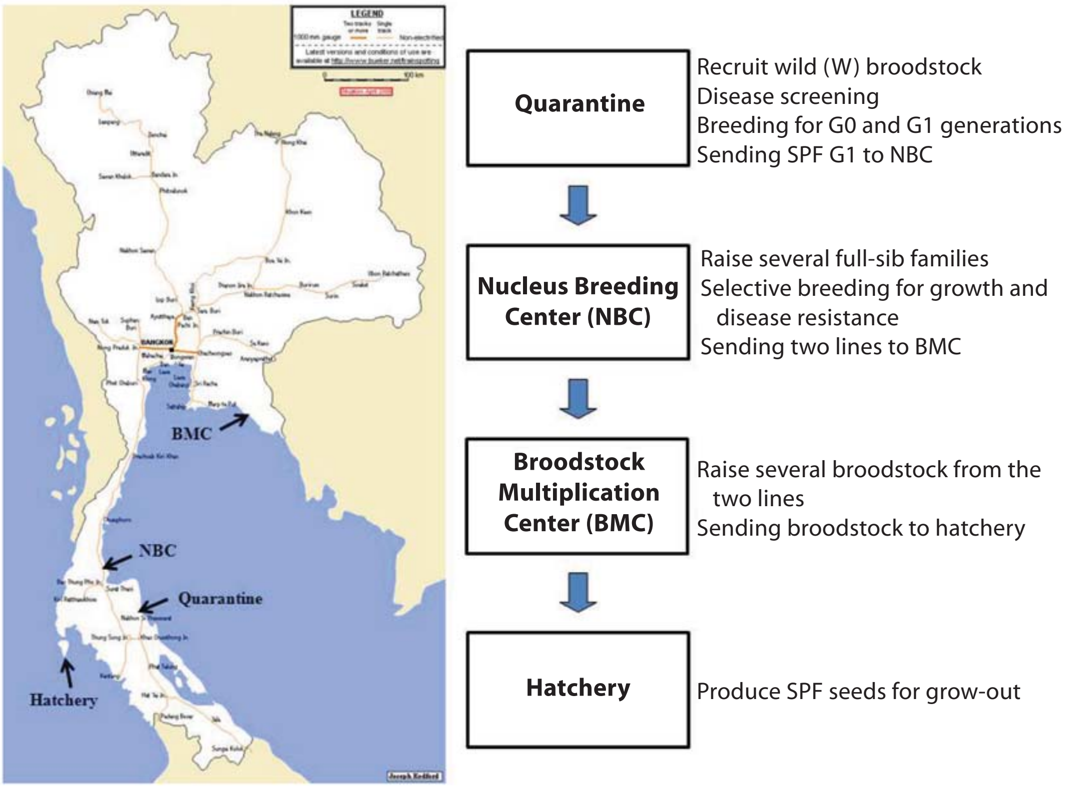


Figure 1 Sites of the production of SPF, selectively bred *Penaeus monodon* broodstock in Thailand

For all the three units, the construction of biosecurity facilities began during 2005 and the first generation of SPF *P. monodon* was produced in 2008. The breeding programme has been operating continuously since then and reached the seventh generation of broodstock in 2015. Strict biosecurity is developed in the three units, especially in the SGIC (being the NBC). Biosecurity is set up through the construction of physical barriers to avoid pathogens and through raising mental awareness of workers so that workers refrain from any act that might introduce pathogens into the rearing area. Pathogens could be introduced to the biosecurity area not only from human traffic but also by shrimp broodstock themselves. Therefore, wild broodstock is strictly prohibited inside the SGIC and only those reared from SPF seed are allowed in the centre. Since genetic varieties of broodstock are essential for successful breeding programmes, wild broodstock from different geographical regions provide base populations for selection. Wild *P. monodon* are quarantined and screened for major shrimp pathogens prior to use as broodstock. Only those *P. monodon* that are found free from pathogens (termed "W" generation) are used to produce the first generation of offspring, termed "potential SPF" offspring. These are reared to become the first generation (termed "G0" broodstock), which is used to produce postlarvae. The postlarvae, if proven to be free of pathogens, are brought into the SGIC. By that process, only SPF postlarvae,"G1" generation, from the quarantine is brought into SGIC where they are reared to broodstock. The complete growth cycle from post larvae to sexually mature broodstock takes approximately one year.

Several genetically unrelated "families" of the broodstock are required for the breeding programme in order to minimize inbreeding depression (Doyle, 2014). Therefore, several SPF full-sib families (as postlarvae) are brought from the quarantine to the SGIC. These families are reared to broodstock and crossbred to produce offspring. The process of rearing to broodstock and crossbreeding has been continuous in SGIC and at the sixth generation, two different genetic lines of postlarvae were selected and sent to the BMC. The postlarvae of each line were raised to broodstock and crossbred to produce postlarvae for farmers. In every generation, two such lines are sent from the SGIC to the BMC and the process is repeated and continued.

1.1 Pathogen screening

Wild broodstock was collected from different geographical regions to ensure adequate genetic diversity. However, for economic reasons, the majority of broodstocks were taken from Thailand, either from the Andaman Sea or from the Gulf of Thailand. A few families were brought from the Philippines, Malaysia, Indonesia, and East Africa. These wild broodstock were quarantined and currently are being screened for nine viruses, two types of protozoa and one bacterium (Table 1). These pathogens differ in their virulence, some can cause mass mortality (e.g., WSSV, YHV and AHPND-inducing bacteria), some may not cause any obvious signs/symptoms in the shrimp unless there is a heavy load of the pathogens (e.g. gregarine and MBV).

The pathogen screening is carried out by the polymerase chain reaction (PCR) method, which, in case of RNA virus, is reverse transcriptase polymerase chain reaction (RT PCR). The methods and their recent modifications, such as the more sensitive and precise loop-mediated isothermal amplification (Arunrat *et al*., 2014), allow the identification of hidden infections in the broodstock without killing them. Screening results indicated that more than 60 percent of the wild broodstock is infected by at least one pathogen out of the list of pathogens tested. The pathogens most frequently discovered in such apparently healthy wild broodstock are MBV, HPV, IHHNV and LSNV. These viruses cause slow growth of *P. monodon*, depending on the viral load and site of tissue damage in the shrimp (Rajendran *et al*., 2012; Sukhumsirichart *et al*., 2002; Withyachumnarnkul *et al*., 2006; Pratoomthai *et al*., 2012), but usually do not cause mass mortality in the infected shrimp. The two most dangerous viruses, i.e. WSSV and YHV are found less in the wild broodstock, probably

Table 1 List of pathogens in penaeid shrimp needed to be eliminated to create specific pathogen-free (SPF) broodstock

Pathogen	Type	Abbreviation	Level of virulence
Gill-associate virus	RNA virus	GAV	C1
Gregarine	Protozoa		C3
Hepatopancreatic parvovirus	DNA virus	HPV	C2
Infectious hypodermal and haematopoietic necrosis virus	DNA virus	IHHNV	C2
Infectious myonecrosis virus	RNA virus	IMNV	C2
Laem-Singh virus	RNA virus	LSNV	C2
Microsporidia (*Enterocytozoon hepatopanei*)	protozoa		C2
Monodon baculovirus	DNA virus	MBV	C3
Taura syndrome virus	RNA virus	TSV	C2
Vibrio parahaemolyticus, AHPND-inducing isolates	Gram-negative bacteria		C1
White-spot syndrome virus	DNA virus	WSSV	C1
Yellow-head virus	RNA virus	YHV	C1

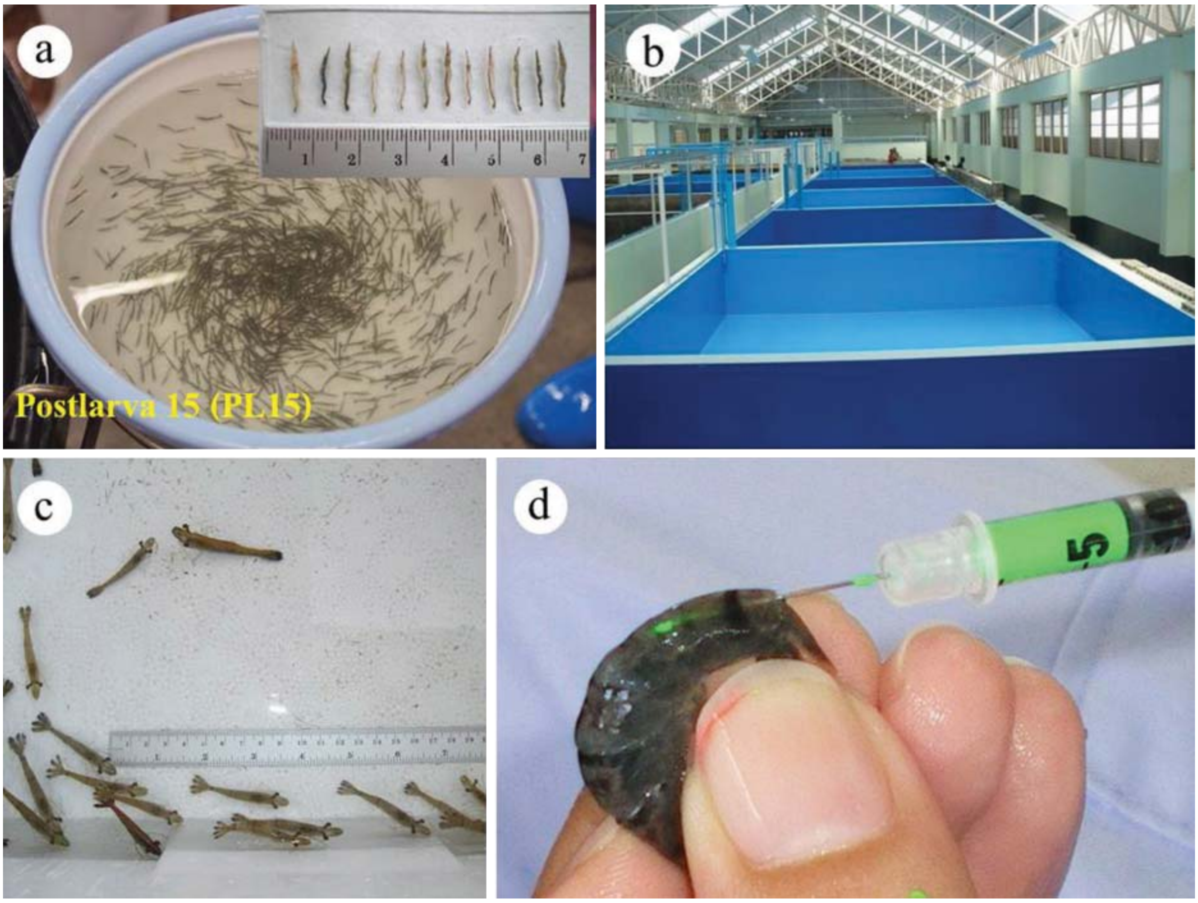
C1 = High virulence, causes mass mortality
C2 = Moderate virulence, causes slow growth, may cause mortality in severe infections
C3 = Low virulence, may cause slow growth, usually causes no mortality

because the shrimp might not have survived the infections. The least frequently detected viruses are TSV and GAV, suggesting that the two viruses may not be endemic in the seawater around Thailand. Another pathogen that was rarely reported in the past but has become more common is the microsporidia *Enterocytozoon hepatopanei*. This pathogen may be associated with slow growth in *P. monodon* (Tourtip *et al*., 2009) and probably in *L. vannamei*.

To ensure SPF status in the NBC and in the BMC, the pathogen screening was periodically performed in postlarvae, juveniles, sub-adults and adults of all the families and in all the generations. Even if only one type of pathogen is detected, all the cohort shrimp would be eliminated by chlorination. Adequate care is taken to avoid any contamination during the elimination process.

1.2 Breeding programme

Offspring at postlarvae stage 15 (PL15) from different families are stocked separately in concrete tanks (5 m × 5 m × 1 m size) and are reared for 1 to 2 months. During this time the PL attain approximately 1 g size (Figure 2). Each tank contains approximately 1 000 shrimp. These shrimp are then, individually, given an intramuscular injection with visible-implanted elastomer (VIE), one family per colour or per combination of colours; the tag stays in the shrimp muscle until the shrimp reach sexual maturity. The VIE-tagged shrimp from different families are then reared in a common pond (800 m^2 polyethylene-lining pond), at the stocking density of 30 to 40 individuals/m^2, which is a standard intensive stocking density for commercial purpose (Figure 3). The shrimp, up to ten families, are reared in the same pond and thus under the same communal environment for three to five months. Periodically, they are randomly sampled and individually weighed and the data on average body weights (± standard deviation) and survival rate are compared among families. In this way, the performance of shrimp from different families is compared under the same rearing conditions. Besides the physical tagging, molecular tagging is performed in each family using microsatellite DNA markers. The molecular tagging and data can be used in future genotypic selection (Benzie, 2009).



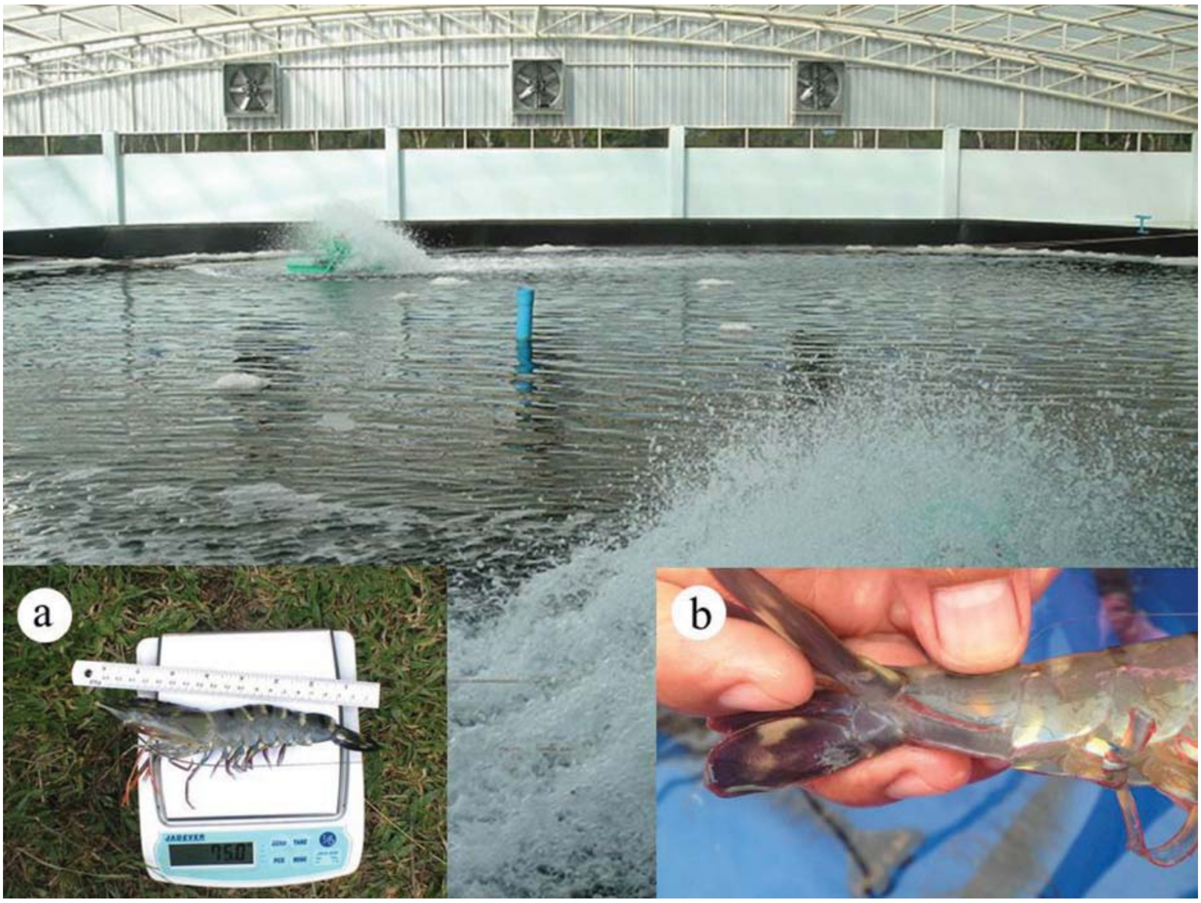
Note: (a) Families of SPF postlarvae 15 (PL15) (b) are reared in separate concrete tanks (c) for 1 or 2 months to grow to about 1 g size before (d) physical tagging by intramuscular injection of visible implanted elastomer (VIE)

Figure 2 Family separation and physical tagging in early stage of SPF *P. monodon* in SGIC

In addition to the selection for fast growth, selection for families with disease resistance has been attempted. The first and the only target thus far is "WSSV-resistant" *P. monodon*. Different families of the shrimp are randomly sampled and challenged with WSSV in a place 50 km away from the SGIC to avoid contamination with this deadly virus. Initial findings suggest that different families may have different "times-to-death" following WSSV challenge, but none has survived the infection. Current studies on viral nucleotide insertions into *P. monodon* genome show promising results regarding a possibility that the shrimp may be able to produce innate double-stranded RNA or micro RNA to destroy the invading virus.

After they become adults (9 to 12 months in culture), 30 percent of the largest sized shrimps from individual families are selected as breeders. As mentioned previously, inbreeding is avoided by crossing only unrelated full-sib families using artificial insemination. The criterion for fast growth of the shrimp family is the average body weight at five months in culture, not the size of the broodstock at nine to twelve months. At five months, the average body weight is in the 25 g to 40 g range, which is probably the best marketable size for *P. monodon* in order to avoid the competitive price of *L. vannamei* that are usually sold at 15 g to 20 g size.

In grow-out farms, the criterion for fast growth is probably not the body weight of the shrimp at five months, but rather the shortest duration in culture in which the shrimp grow to the desirable marketable size. For instance, farmers prefer the shrimp that have reach 30 g size within three months in culture rather than those that require four months. Evidently, the shorter duration reduces investment in feed and husbandry and at the same time lowers the risk of losses because



Note: After VIE tagging, five to ten families of SPF *P. monodon* are stocked in the same pond. At five months in culture, the shrimp in each family are individually determined for body weight (inset "a") and, after harvest, survival rate of each family is calculated. Each family is identified by a physical tag (inset "b").

Figure 3 Comparison of growth and survival rate among families

of crop failure. Therefore, the criterion of fast growth in the breeding programme should be the shrimp that require the least amount of time to reach marketable size. However, in practice, it is more convenient in the NBC to use average body weight of families per fixed amount of time in culture as the criterion.

By family selection, each generation of the shrimp has a faster growth rate than its parental generation. The average daily growth within 150 days for G6 generation was at 0.19 g/d, compared to that of the G1 generation at 0.13 g/d. This means a 46 percent increase in growth rate within five generations, or roughly 9.2 percent per generation. This growth rate, 0.19 g/d, is considered not very impressive for genetically improved *P. monodon*. However, for technical and biosecurity reasons, the shrimp are first reared in the concrete ponds for family separation before VIE injection, followed by being reared in a polyethylene-lined pond, which is not the optimum culture environment for *P. monodon* grow-out. From the fifth generation onward, mass selection has been performed in addition to the family selection. This is carried out by stocking PL15 from several selected families directly into the polyethylene-lined pond without physical tagging. The growth rate at five months in culture has been improving and most families have the growth rate >0.2 g/d. When the same batch of shrimp is reared in commercial earthen ponds, the growth rate is found to be in the range of 0.25 g/d to 0.30 g/d (Ruangsri, pers. comm.), which is considered better than the performance of seeds generated from wild broodstock. Complete data on the earthen pond performance of the seeds produced from SGIC are under study. The feedback data are used for further management of the breeding programme.

1.3 Commercial aspect of SPF broodstock production

As genetically improved SPF broodstock are produced under high investment, the SPF seed normally outperforms seed generated from wild broodstock. Therefore many owners of grow-out farms have a tendency to select fast growing individuals from the stock after selling their marketable sized shrimp and further rear these shrimp to become their own broodstock. The authorized breeders of the SPF seed have to prevent this by distributing seed from a single line of broodstock. If unauthorized breeders rear these shrimp to become the next-generation broodstock, further breeding of these broodstock would result in inbreeding depression (Moss *et al*., 2007). The offspring would either grow slowly or have a low survival rate or both. Commercially, this practice is considered fair because it protects the right of authorized people who invest in the production of high-quality broodstock. It is also scientifically reasonable because the practice prevents damage to the shrimp farming industry if farmers stock seed generated from the single-lined broodstock and subsequently have inbreeding depression and an unfavorable crop. This prevention mechanism, however, as can be seen from what has happened in the case of *L. vannamei* broodstock production, has not proved successful as inbred SPF *L. vannamei* seed from closely related broodstock are widely distributed in Thailand, Ecuador and in many other countries (Doyle, 2014).

Because of the failure to prevent stocking inbred seeds, one of the possible alternative approach will be to provide two unrelated lines of seed or broodstock to any investors who produce outbred seed for grow-out. The farming community should be made aware of these two lines to prevent or to minimize the chance of producing the inbred seed. By doing this, SGIC would provide two lines of high-quality seed to commercial BMC, or two lines of broodstock to commercial hatcheries. This operation will make SGIC a broodstock provider, not a seed provider. However, this approach may not be commercially feasible as the numbers of seed required for the two lines of broodstock are not sufficient to be profitable. In this scenario, commercial BMCs may survive, but not the NBC. Therefore, the NBC should be a non-profit organization, and since SGIC is government-owned, it should be able to assume this role.

1.4 Success and failure from SPF seeds

Two selected lines of PL15 were sent to two BMCs: one belongs to the government and the other belongs to the private sector. The seed is reared to sexually mature broodstock, which are sold to a commercial hatchery. The seed is produced in compliance with the standards set by the Department of Fisheries, Ministry of Agriculture, Thailand. In early 2015, the hatchery produced and distributed 10 million to 15 million SPF *P. monodon* seed per month to grow-out farms. The amount of seed disseminated is still at the level of 10 percent of the seed demand.

Performance of the seed has been followed up in commercial shrimp farms. Under the current endemic situation of AHPND and WSD in Thailand (January–May, 2015), the grow-out success is approximately 50 percent, regardless of the source of seed. In one survey, it was found that 20 percent of the cases of failure was from WSD and 80 percent was from AHPND (Ruangsri, pers. com.). Attempts to avoid the diseases have been employed in many farms. The methods are adapted from the results of scientific research, as well as based on empirical reasons. In general, two opposite methods are employed: the clear-water method and the turbid-water. In the first method, nutrients for *V. parahaemolyticus* and other AHPND-toxin producing bacteria are reduced by frequent removal of sediments from the pond bottom. The frequency of removal is as high as four or five times a day, or at two hours after each meal provided. The second method is employed with the rationale that by increasing the population of beneficial bacteria in the pond they may be able to compete against AHPND-inducing bacteria. Therefore the pond is either supplied with probiotics or by using biofloc technology, thus the water becomes turbid. This approach and/or the tilapia co-culture method is supported by a number of scientific studies (Browdy *et al*., 2014). The method employed may create a "mature and balanced" biota in the pond by as yet unclear mechanisms to prevent the disease (Schryver *et al*., 2013).

To prevent WSD, educated farmers usually employ some degree of biosecurity to prevent entry of WSSV-carriers into the farms. The carriers, WSSV-infected crustaceans, may come with the water or from an infected shrimp that birds take from an infected pond and accidentally drop into an uninfected pond while flying over it. Thus far, the most effective WSD prevention method is to employ a polyethylene-lined pond to prevent WSSV-contaminated water from outside and by covering the pond with a net to prevent any dropped shrimp carcass from falling into the pond. This prevention method, however, is too expensive for most shrimp farmers.

Therefore SPF seeds that are free from WSSV and from AHPND-inducing bacteria cannot guarantee successful grow-out production. Needless to say, both SPF seeds and proper grow-out management are required to achieve success. For such successful grow-out farms, the farmers are satisfied with the performance of SPF *P. monodon* seed, especially in terms of the growth rate and size distribution.

2. Impact on the shrimp farming industry

In 2013, a small number of Thai shrimp farmers began *P. monodon* farming again after a long pause of farming this species. This followed the failure of *L. vannamei* culture that was affected by AHPND. However, this revival is associated with some skepticism and feeling of uncertainty as the disease also kills *P. monodon*. Some farmers still culture *L. vannamei*, employing new methods described above, in the hope of avoiding AHPND. It may be difficult to state with accuracy the proportion of total shrimp production in Thailand contributed by shrimp farmers who grow *P. monodon*. But it is quite accurate to say that *P. monodon* farming has increased during the past few years. The demand for *P. monodon* seed in early 2015 witnessed an increase of 200 million to 300 million a month, which is about ten times more than that in the same period of 2014.

In the past, wild broodstock was the only source of *P. monodon* seed but since 2013 at least three private companies and one government agency (SGIC) have produced domesticated, selectively bred, SPF *P. monodon* seed with improved and predictable performance. A large number of Thai farmers prefer seed from the SPF broodstock to those from the wild broodstock. Three important characteristics that farmers require are: fast growing (about 30 g within four or five months in culture), high survival rate (>60 percent) and high red-colour index after boiling. All these qualities are met to a large extent by SPF seeds from domesticated, selectively bred broodstock.

Nevertheless, export remains the prime target of *P. monodon* shrimp growers (the People's Republic of China is the main importing country) since live *P. monodon* fetches a higher price than frozen shrimp. The shrimp are shipped by air cargo as cold-anaesthetized in moist foam-boxes without seawater and are revived after arrival at the destination. Meanwhile, fresh frozen *P. monodon* are still exported to countries that prefer *P. monodon* to *L. vannamei*, such as the European Union countries and Japan.

It may be too early to say that seeds from domesticated, selectively bred SPF *P. monodon* have provided a significant positive impact on the shrimp farming industry in Thailand. But that may not be the issue since the production of domesticated broodstock has become economically viable and, as time passes, it will become more expensive to use wild broodstock rather than domesticated broodstock. In addition, the performance of the SPF seed from genetically improved broodstock is more stable and predictable than seed from wild broodstock. It is likely that more and more Thai farmers will turn to SPF *P. monodon* seed, the same way as they have been relying on seed from SPF selectively bred *L. vannamei*.

3. Lessons learned

The production of farmed shrimp in Thailand is mostly for export and is in the hands of small-scale farmers and large corporations. The difference between these two sources of production is the culture technologies used. Small-scale farmers who own a few earthen ponds (usually 0.5 ha to 1.0 ha size) have little knowledge of shrimp biology, shrimp diseases and optimum water qualities for shrimp growing, but they grow shrimp by accumulated experience. Conversely, large corporations have access to knowledge and new technologies on shrimp farming that are very dynamic. However, there has not been any comparative assessment of the production per unit investment between these two sectors. Although we can state with confidence that large corporations, because of having better technologies to prevent disease outbreaks, have less incidence of crop failure. But the investment on technologies and personnel is much higher than those of small-scale farmers. Probably, the main difference between the two groups is in terms of their resilience to stay in the business in the event of crop failure. Because of their large resources and diversified investments, large corporations can stay longer despite numerous setbacks, whereas small-scale farmers may not be able to continue their activities after two or three successive crop failures. Many of them lose their farmland to the corporations or other capitalists in exchange for debt on shrimp seeds, feed and others. More and more small-scale farmers have lost their land to capitalists, and thus, as time passes, the country's shrimp production has been transferred from small-scale farmers to large corporations.

However, this does not mean that shrimp production in Thailand is increasing. On the contrary, the production in 2014 dropped to <50 percent of the production in 2012 as a result of AHPND and WSD. With further dropping of the production, large corporations may have to use the land they acquire from small-scale farmers for other types of business, such as real estate. Without their own land to make a living, what will be the future of these small-scale farmers? Will the socio-economic gap between the rich and the poor in Thailand, which is wide already, be wider in the near future?

This large socio-economic difference is obviously not desirable. To prevent this from happening, small-scale shrimp farmers must exist and be able to cultivate knowledge and affordable technologies. Researchers working on shrimp culture technologies and diseases should have a broader view of their research aims. For instance, it is not sufficient to discover a new type of pathogen, mode of transmission and mechanisms of diseases, the knowledge should be followed by solutions to prevent particular diseases in the field, and in a way that the majority of farmers can afford.

We have learned from 30 years of intensive shrimp farming in Thailand that successful shrimp farming depends on more than just having high-quality seed. Farmers also need appropriate culture technologies, environmental awareness, well-planned marketing, well-planned financial management and others. High-quality seed is one critical requirement, but without other factors, it is unlikely to have a good outcome. Therefore, the provision of SPF seed must be accompanied by appropriately affordable technologies to reduce the risk of crop failure. Co-operation and collaboration among farmers and other stakeholders are needed. Mutual trust and good communications are essential to drive the whole process of farmed shrimp production from high-quality seeds to marketable sized shrimp.

4. The way forward

The production of SPF seed is a long-term process that requires continuous planned breeding programmes that are designed to improve traits and maintain genetic gains on a continuous basis. As new diseases appear, new strains of seed that are resistant to the new pathogens are needed. New generations with better growth and more disease resistance have to be continuously sought after.

In accomplishing the goal mentioned above, a continuous supply of gene pool of wild broodstock from various geographical sources must be periodically recruited. Wild broodstock, or postlarvae of wild broodstock, will be brought into the quarantine. This operation, however, would "dilute" the high growth rate and disease-resistance traits of the already-genetically improved stock. This effect would be short-term and will fade away after a few generations of the shrimp, which have additional favourable traits. With proper management in the breeding programme, the continuous supply of genetically improved stock suitable for stocking at any point in time would increase the rate of crop success.

Although environmental awareness has been mentioned only briefly in this paper, its importance cannot be overemphasized. This aspect has been addressed widely in the literature, but what is more important is the implementation, which is rather limited. Environmental awareness in shrimp culture regarding proper use of land for farming (no mangrove destruction, for instance), discharging of rearing water into bioremediation ponds before letting out to natural waterways, etc., has been addressed in the literature. In the context of SPF *P. monodon* seed production, there probably needs to be wide debate about the adverse impact on the environment and ecology as a result of the escape of genetically improved shrimp into the wild.

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Country Paper 4: Successful development and dissemination of mass grouper seed production technology in Indonesia

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Abstract

Gondol Research Institute for Mariculture (GRIM) in Bali, Indonesia, which changed its name to Gondol Research and Development Institute for Mariculture (GRDIM) in 2010, has conducted research on the artificial propagation of groupers since 1995. In 2001 GRIM began successfully producing grouper seed on a commercial scale. Its hatchery techniques, developed by GRIM, which address broodstock maintenance, spawning, larval rearing and nursery culture, have been adopted widely by the private sector and government hatcheries for several grouper species such as humpback grouper, *Cromileptes artivelis*, tiger grouper, *Epinephelus fuscoguttatus,* flowery grouper, *E. polyphekadion*, estuarine grouper, *E. coioides*, coral grouper, *E. corallicola*, potato grouper, *E. tukula*, giant grouper, *E. lanceolatu*s, coral trout, *Pletropomus leopardus* and also grouper hybrids, crossing between male *E. lanceolatus* × and female *E. fuscoguttatus,* and crossing between female *E. fuscoguttatus* and x *male E. polyphekadion*.

Two types of hatcheries developed by GRIM are the complete hatchery (CH) and the backyard hatchery (BH). At present, there are 21 units of CHs and 536 units of BHs surrounding GRDIM and Situbondo Coastal Aquaculture Development Center (CADC), which provide jobs and income for 2 000 people. Production of grouper seed for various species ranged between 12 million/year and 20 million/year and almost 90 percent of seeds was exported to neighbouring countries.

To achieve sustainable production of grouper seeds, there is definitely a need to improve research quality and technical capability of researchers and technicians of private hatcheries. Groupers seed production research should be assigned priority to continue refinement of developed technologies, the development of standardized methodologies and techniques for domesticating groupers and vaccine development for the treatment of viruses.

Introduction

Groupers are commercially important fish particularly for live seafood markets in Asia-Pacific countries including Indonesia, Singapore, Malaysia, Philippines, Viet Nam, Thailand, Taiwan, Province of China, China and Australia. Species that are commonly found in the seafood markets belong to three genera: *Cromileptes, Epinephelus* and *Plectropomus* (Rimmer *et al.,* 2004). Because of the high prices that groupers bring in the markets, there is considerable interest in commercial aquaculture production of a range of grouper species. However, inconsistent supply of seed is one major constraint associated with grouper aquaculture. In 1998, nearly 12 000 *Cromileptes altivelis* and 9 000 *Epinephelus fucoguttatus* larvae were first produced through natural spawning and artificial larval rearing (Suguma *et al*., 1999 and 2000) in the tanks of GRIM. After that the seed production and aquaculture industry rapidly grew in Indonesia and grouper production increased from 6 300 MT in 2009 to 12 400 MT in 2014 (Anon., 2015).

Hatchery techniques developed at GRDIM can be used to produce juveniles of several species of grouper and hybrids (Sugama *et al.,* 2014). The hatchery techniques developed by GRDIM have now been adopted widely by five public hatcheries belonging to the government and several private sector hatcheries.

In Indonesia, supplies of grouper seed are sufficient to meet the demand for local grow-out farmers. At present there are five public grouper hatcheries within Indonesia: Batam Mariculture Development Center (Batam MDC), Lampung Mariculture Development Center (Lampung MDC), Lombok Mariculture Development Center (Lombok MDC), Ambon Mariculture Development Center (Ambon MDC) and Situbondo Coastal Aquaculture Development Center (CADC). Technology developed at GRDIM has been a strong stimulus for commercial hatchery development in the surrounding area. In northern Bali's Buleleng Regency and in Situbondo Regency in East Jawa, there has been a steady increase in the number of hatchery tanks being used to produce grouper fingerling.

Millions of grouper fingerlings of various species have been marketed not only in the domestic market but also exported to neighbouring countries, including Singapore, Malaysia, Thailand, Viet Nam, Taiwan, Province of China , Hong Kong SAR and China.

This paper describes the grouper hatchery techniques developed at GRDIM that have now been transferred to the private sector contributing to farmers' incomes and job opportunities as well as export earnings.

1. Broodstock, spawning and hybridization

1.1 Broodstock

Broodstock tanks are used not only for culture and maintenance, but also for spawning. Because the size of grouper broodstock differ among species and range from 1.0 kg to 80.0 kg, larger tanks in the range of 60 m^3 to 150 m^3 are preferred. Based on experiences at GRDIM, tanks should be round, or square or rectangular shape with rounded corners. Medium-range blue or grey is preferred tank colour. There is general agreement that the depth of tanks should be at least 2.0 m and preferably 2.5 m with water inlet and outlet systems and aeration. Each tank should have an overflow pipe with a tank and nets installed for eggs collection. At GRIM, broodstock tanks are continuously supplied with fresh seawater at daily exchange rates of 200 percent to 300 percent and natural photoperiod. The water must be clean and clear with stable salinity of 33 ppt to 35 ppt and temperature of 27.0°C to 30.5°C.

Broodstock are fed to satiation six times a week – four times with "trash" fish (mainly *Clupeidae* and *Scombridae*) and two times with squid. The feed is supplemented with a vitamin mix at 1.0 percent of feed volume (Sugama *et al*., 2001). Commercial or custom-formulated vitamin mixes can be used (Sugama *et al*., 2009). Faeces and excess feed are siphoned out at regular intervals. It is advisable to clean broodstock tanks after spawning, usually during the full moon phase. To prevent infestation with *Benedenian* and *Cryptocaryon* parasites, a fresh water bath of broodstock for five to seven minutes during tank cleaning is recommended (Koesharyani *et al*., 2001).

1.2 Spawning

Grouper are protogyneous hermaphrodites that mature as females and then change into males at a later age. Broodstock sex determination can be easily done during new moon periods. Male fish are characterized by white milt oozing from the genital pore by gentle pressing of the abdomen from the head toward the tail. Mature females have swollen abdomens containing eggs that can be sampled through the genital pore by canulation.

Except for *E. lanceolatus*, the broodstock of all other grouper species spawn naturally in tanks. Spawning generally occurs at night (21.00 hours to 03.00 hours) for consecutive three to six nights in each month during the new moon phase. At GRDIM, grouper broodstock generally spawn throughout the year (Sugama *et al.,* 2012). During the spawning period, *C. altivelis, E. poliphekadion* and *E. corallicola* may spawn between 0.4 million to 2.6 million eggs each night and *E. fuscoguttatus, E. coioides and E. tukula* spawn between 0.6 million to 0.8 million eggs each night. In Eastern Indonesia (Bali, Lombok, Sumbawa) in July up to the middle of September, cooler southerly winds cause water temperatures to drop to about 25ºC and during this period grouper broodstocks usually cease spawning. If they do spawn during this period, only a small number of poor quality eggs are produced and these are not suitable for hatchery seed production.

When spawning occurs, eggs are collected from the overflow eggs collector tank using a fine (400 µm mesh) net (Figure 1). The fertilized eggs of grouper are non adhesive and pelagic, egg diameter ranges from 0.8 mm to 0.9 mm. Grouper eggs are sensitive to handling during the early developmental stages, and should only be removed from the collection nets once the embryo has developed optic vesicles, which is in the early stage of eye development. Handling eggs before this stage will result in higher mortality and a higher incidence of deformities (Sugama *et al.,* 2012).

Figure 1 Eggs collector, eggs washing and fertilized eggs floating

Only floating eggs are used for larval rearing because these are more likely to be fertilized than sinking eggs, which are unfertilized or dead. The unfertilized eggs settle to the bottom of the broodstock tank and are removed by siphoning. If any unfertilized eggs are inadvertently transferred to the incubation tanks, they should be siphoned out and discarded to prevent degradation of water quality.

The quality of grouper eggs is generally evaluated using both qualitative and quantitative methods. Fertilized eggs are examined under a microscope with 10 × or 20 × magnification, which is sufficient to evaluate the quality of the eggs. Good quality eggs that can be used for larval production, should have characteristics such as being regular in shape, during the early stage of embryonic development the individual cell should be regular in size, eggs and embryos should be completely transparent with no dark areas, and chorions (egg shells) free from any parasites or fouling organism. If a low proportion of eggs do not conform to these characteristics, the eggs can still be used in the hatchery because it is likely that poor quality larvae will simply die during the larval rearing procedure. If there is high proportion of eggs exhibiting abnormal characteristics (>10 percent), the batch should be discarded. If the eggs have parasites or fouling organisms, the batch should be cleaned and disinfected with 100 mg/L to 50 mg/L chorine.

Fertilization and hatching rates are also used as indicators of egg quality. For grouper, both fertilization and hatching rates should be higher than 80 percent and preferably higher than 90 percent. Fish larvae from batches of eggs with poor fertilization and hatching rate less than 30 percent are regarded as being poor quality and generally result in low survival rates and high incidence of deformities. Such batches are usually discarded. Records of fertilization and hatching rates should be maintained to allow an evaluation of broodstock performance and spawning success, particularly on an annual basis. Estimation of the fertilization rate should be undertaken at least six hours after fertilization and well before hatching and embryonic development makes fertilized eggs easier to discriminate. The grouper eggs hatch between 18 hours and 24 hours after fertilization at 27.5ºC to 29.5ºC. To measure the fertilization rate successfully, it is necessary to be able to distinguish fertilized from unfertilized eggs. This requires a good microscope and some experience to differentiate fertilized eggs during the early developmental stages.

Because the dead eggs, live eggs and hatched larvae distribute differently in the tank, it is necessary to mix the eggs and the larvae in the tank by swirling the water in the tank by hand before the sample of the eggs and larvae is drawn for calculating the hatching rate. Swirling should be adequate to fully mix the eggs and larvae, but should not be so violent as to damage the newly hatched larvae. Beakers or small containers that are used during sampling must be disinfected before use. The grouper eggs are directly stocked to the larval rearing tanks before hatching and hatching rates are estimated with separate samples of the larvae, not those intended for use in larval rearing. Therefore, estimation of the hatching rate should be recorded when complete hatching has taken place.

1.3 Hybridization

Genetic improvement of grouper is important for developing disease resistance and producing strains with a high growth rate. In GRDIM, hybridization has been undertaken to improve the seed quality. *E. lanceolatus* significantly grows faster than *E. fuscoguttatus.* GRDIM's experience is that the spawning of *E. lanceolatus* in captivity has failed most of the time, but milt is easily collected from mature males by striping. Therefore, this gave an opportunity to hybridize male, *E. lanceolatus* and female *E. fuscoguttatus* to increase the growth rate (BPBAP Situbondo, 2012). Similarly, hybridization is done between male *E. polyphekadion* and female *E. fuscoguttatus* to increase growth rate and disease resistance. *E polyphekadion* is more resistant to environmental stress and diseases compared to *E. fuscoguttatus* in hatchery conditions (James *et al.*, 1999). Larval developments of hybrids of both *E. lanceolatus* × *E. fuscoguttatus* and *E. polyphekadion* × *E. fusoguttatus* are normal (BPAP, 2012; Ismi *et al.,* 2013). Growth rate of hybrids of *E. lanceolatus x E. fuscoguttatus* grew faster than E. *fuscoguttatus* and slower than *E. lanceolatus* and hybrids of *E. polyphekadion* and *E. fuscogutatus* is more resistant to diseases and environmental stress compared to both parietals (Sugama *et al.,* 2014).

1.4 Larval rearing

At GRDIM both round and rectangular tanks are used for larval rearing. For rectangular tanks, the corners of the tank should be rounded to avoid larval aggregation in the tank corners. The preferred size of larval rearing tanks is about 10 m^3 in volume with a depth of 1.2 m. Based on experience in rearing grouper larvae of several species at GRDIM, the preferred colour for larval rearing tanks is bright yellow. This colour allows the grouper larvae to discriminate prey such as rotifer, copepods nauplii, and brine shrimp more easily, and makes tank management, particularly cleaning, easier (Figure 2) (Sugama *at al*., 2008). The larval-rearing tanks should be maintained at a separate quarantined area within the hatchery, with entry only to authorized persons after following the necessary disinfection procedures.

Figure 2 Yellow coloured larval rearing tanks for grouper

Sea water used for the larval-rearing tanks is pretreated in a sand filter. The water salinity range 34.0 ppt to 35.0 ppt and water temperatures 28.5ºC to 30.5ºC. Newly hatched larvae are stocked at an initial density of ten larvae/L. Live food for the larvae consists of microalgae (*Nannocholopisis*), rotifer-SS and S types and *Artemia nauplii*. The larval rearing protocol is summarized in Figure 3.

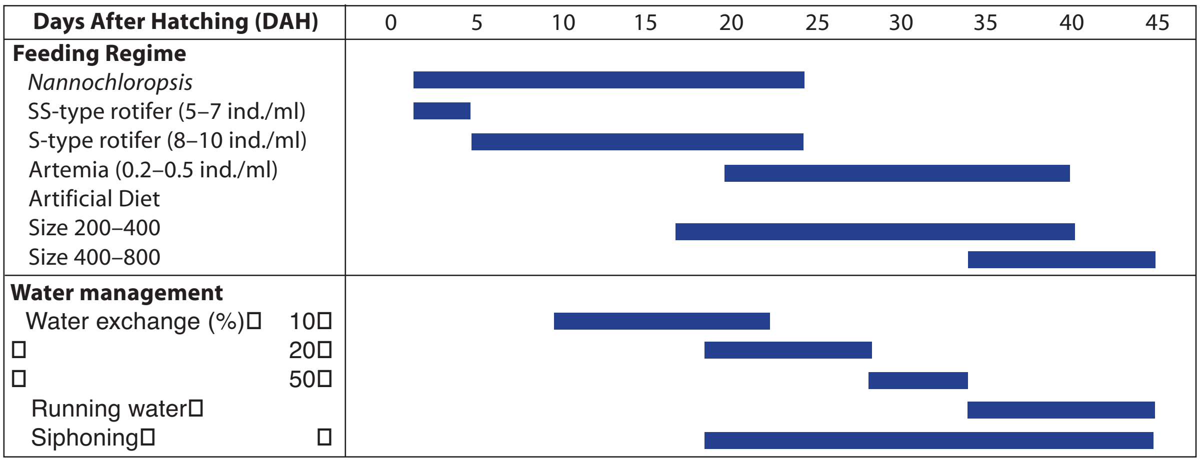

Figure 3 Larval rearing protocol for groupers

1.4.1 Main problems contributing to larval mortality

There are several problems in mass seed production of grouper, the main problems that usually occur are:

- **Poor quality of eggs**

Fertilization and hatching rates are used as an indicator of eggs quality. Our research has demonstrated that improving the nutritional composition of food fed to grouper broodstock resulted in good fertilization rate, hatching rate and quality of newly hatched larvae. Broodstock fed by food (trash fish and squid) that is not too fresh may cause poor quality eggs.

- **Failure of initial feeding**

Experience in mass production of grouper seeds indicates relatively high mortality among first-feeding larvae. Stomach content of larvae should be checked under a microscope about the time of initial feeding (3 DAH) to ensure that they are feeding on the rotifer provided. If the larvae are not feeding, check the size and density of the live food organisms to ensure that there are enough food items commensurate with the size of the larvae.

- **Long spine**

Grouper larvae are attracted to patches of sunlight in the tank, and where patchy sunlight is present may swim to the surface of the tank. This often results in the larvae becoming "stuck" on the water surface or a group of larvae becoming entangled in each other's spines. Both problems cause significant mortality among early stage larvae. To reduce these problems, only indirect light should fall evenly on the larval-rearing tanks. All direct light should be screened. To prevent surface tension death, squid oil can be added twice daily to the tanks at about 0.2 ml/m^2 to form a thin film at 1 to 5 DAHs (Yamaoka *et al*. 2000: Sugama *et al.,* 2001).

- **Viral Nervous Necroses (VNN) and Iridovirus**

VNN and Iridovirus are the two most important viruses causing high mortality in grouper. VNN is a devastating disease that leads to massive mortalities in larvae and juveniles of groupers. Researchers at GRDIM have proved that VNN may be transmitted vertically, from broodstock via egg and sperm. Eggs taken from female broodstock by canulation and tested by PCR (Koesharyani and Novita, 2006) were positively infected by VNN. VNN is also transmitted horizontally through water introduced to larval-rearing tanks or in live food culture. Our research suggests that most outbreaks of VNN in marine finfish hatcheries in Indonesia are because of horizontal transmission (Koesharyani *et al.,* 1999). Cases of iridovirus infection in juvenile grouper have been reported in Indonesia (Zafran *et al*., 2000; Koesharyani *et al*., 2011; Mahardika *et al*., 2001). Strict biosecurity is the best defence against outbreaks of VNN as suggested by Hick *et al*. (2011).

- **Cannibalism**

After 45 DAHs almost all larvae metamorphose to the early stage of juveniles and cannibalism can be a challenge in the larval-rearing tanks. This phenomenon is common for grouper species. However, in order to reduce cannibalism, food must be made available to the juveniles every morning at first light. Feeding the fish frequently, every one to two hours, also helps to reduce cannibalism. After 50 to 60 DAHs, the fish should be graded and similar sizes should be kept in the same tank.

2. Nursery culture

Grouper juveniles harvested from larval-rearing tanks are too small (usually a total length of 2.0 cm to 2.9 cm) and weak for sea cage culture. Nursery culture is conducted to grow them to the commercial size of 8 cm to 10 cm. When juveniles are stocked in nursery tanks, they usually gather near drain filters and then settle to the bottom during the first few days. Therefore, tanks with volumes of 5 m^3 to 10 m^3 are suggested for nursery culture because these sizes are easy to manage. A density of 500 juveniles/m^3 is suitable for stocking density (Sim *et al.,* 2005). Nursery culture in floating cages may be possible, but grouper juveniles are very sensitive to physical disturbances such as wind and waves.

Juveniles can be fed on small shrimp and minced or chopped "trash" fish. Those juveniles grown in sea cages must receive "trash" fish until marketable size. To feed the juveniles on dry pellets, feeding on an artificial diet should be habituated during the nursery culture itself. There are several types and sizes of commercial diets for grouper. Based on the results of fish nutrition research at GRDIM, the nutritional requirements for juvenile groupers are presented in Table 1. (Giri *et al.,* 1999; Giri *et al.,* 2006; Suwirya *et al.,* 2006). At GRDIM, the fish are fed daily until satiation at 07.00 hours and 10.00 hours, and 14.00 hours and 17.00 hours. The juveniles attain a size of 8 cm to 10 cm after six to eight weeks of culture. The smallest size of juveniles recommended for stocking in a sea cage for further growth is 8 cm length.

Table 1 Nutritional requirements for grouper juveniles

Nutrient	*C. altivelis*	*E. fuscoguttatus* *E. polyphekadion*	*E. coioides*	*P. leopardus* *E. corallicola*	*E. lanceolatus* *E. tukula*
Protein (%)	54	47	48	47	47
Fat (%)	9–12	8	10	9	8–12
n-3HUFA (%)	1.4	1.5	1.5	1.5	1.4
Vitamin C	30 mg/kg	30 mg/kg	30 mg/kg	30 mg/kg	30 mg/kg

3. Technology transfer and dissemination

Researchers at GRDIM (known as GRIM until 2010) have been researching artificial propagation of groupers since 1995. GRDIM has been successfully producing grouper seed stock at commercial-scale level since 2001. Hatchery techniques, which address broodstock domestication, spawning, larval rearing and nursery culture, have been adopted widely by the private sector for several grouper species as mentioned above.

There are two types of marine hatcheries developed in surrounding GRDIM areas. These are complete hatcheries (CHs) and partial hatcheries, or backyard hatcheries (BHs), which are a type of partial hatchery. BHs have been designed to hatch and rear fertilized eggs until selling time whereas CHs perform broodstock maintenance, maturation, spawning, live feed culture, larval rearing and marketing. BH buy fertilized eggs from CHs.

The development of the BH technology for milkfish, and subsequently groupers, was a product of GRIM. In order to accelerate transfer of technology, BHs for milkfish were initially established by the staff of GRIM in collaboration with small farmers. Initially, groups of four (usually consisting of two GRIM staff and two local farmers) were organized, with each member contributing a share of capital investment to set up the BHs. Later, additional tanks were added to the set up, or individuals from the groups established their own BHs when they were able to accumulate capital.

The prototype BHs as transferred to smallholders consisted of two roofed 10 MT larval-rearing tanks and associated phytoplankton and rotifer culture tanks. The larval rearing tanks are usually yellow. The prototype BHs also evolved into medium-scale or even large-scale grouper hatcheries as farmers kept on adding larval-rearing tanks for other species of grouper.

At present, the number of CHs in GRDIM and CADC-Situbondo East Java areas was calculated at 21 units and the number of BHs was calculated at 536 units including medium-scale and small-scale. Hatcheries. This activity provides jobs and income for 2 000 people, mostly living along the coastal areas in Northern Bali and East Java. Total production of seeds from CHs and BHs for eight species and hybrids is between 12 million/year to 20 million/year, and approximately 90 percent of production is exported to neighbouring countries such as Singapore, Malaysia, Thailand, Viet Nam, Taiwan, Province of China and China.

4. The way forward

To achieve sustainable production of grouper seeds, there is definitely a need to improve research quality and the technical capability of researchers and technicians of private hatcheries. Groupers seed production research should be assigned priority to continue refinement of developed technologies, the development of standardized methodologies and techniques for domesticating groupers. Determination of physiological requirements for reproductive performance and physiological requirement of larvae and juveniles should be undertaken. Research on a vaccine for controlling VNN should be strengthened and research on the Iridous virus is also urgently needed. In order to implement and transfer refined technology of grouper seed production to private hatcheries effectively, there is definitely a need for close cooperation between government hatcheries and the private sector, including non-governmental organizations.

In its genetic improvement research programme by individual selection, GRDIM has been keeping a second generation of *C. altivelis* and third generation of *P. leopardus*. Research and development is urgently needed to develop standards for seed quality and health maintenance, including the promotion of healthy seed, disease resistance and standards for accreditation of hatcheries or farm suppliers of quality seed, in addition to distribution and licensing standards.

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Country Paper 5: Development and dissemination of low-cost farm-made formulated feed for improved production efficiency in brackishwater polyculture

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Abstract

Extensive brackishwater farming systems depend upon natural seeds and natural productivity with multiple species and production close to 500 to 750 kg/ha/year is practiced in the coastal States of India. In order to achieve sustainable higher production from this system, the Central Institute of Brackishwater Aquaculture (CIBA) standardized polyculture of indigenous brackishwater fish and shrimp using low-cost farm-made feed made up of locally available ingredients. Experiments were conducted in an indoor system, on-farm and at farmers' ponds to standardize polyculture using indigenous brackishwater fish and shrimp species. Polyculture with different stocking densities of *Liza parsia* (5 000/ha), *Liza tade* (5 000/ha), *Mugil cephalus* (2 500/ha), *Scatophagus argus* (2 500/ha), *Mystus gulio* (30 000/ha) and *Penaeus monodon* (2 500/ha) resulted in 4 764 kg/ha production using low-cost farm-made feed (Indian rupee, INR25.32/kg, USD0.41/kg) having FCR of 1.36, in three consecutive trials of 325 days each in farmers' ponds. The farm-made feed (crude protein – 29.77 percent) containing different unconventional ingredients (sunflower cake, mung husk) with 10 percent fishmeal performed at par with that of feed containing 22 percent fishmeal and used in farmers' ponds. Economic analysis revealed a net profit of about INR291 thousand/ha (USD4 693.5/ha) with a benefit–cost ratio of 1.85. Experiments with feeding method standardization suggested that low-cost farm-made pellet feed could be offered at 2 percent to 10 percent body weight per day and the daily ration needs to be distributed in three equal portions in trays in the morning (09.00 hours), afternoon (13.00 hours) and evening (17.00 hours). Every portion must be offered in two split doses at one-hour intervals to meet the requirements of fish of various sizes.

Production improvement of twofold to fourfold compared to the conventional system has been observed and this improved polyculture practice has been disseminated to 57 farmers in West Bengal covering 30 ha. To cater to the increased demand for farm-made feed, the farmers formed a cooperative society and established a pulverizer with the financial help of the State Government. This experience can be shared with countries such as Bangladesh and Myanmar that have similar environmental conditions.

Introduction

Brackishwater farming in India is an age-old traditional system confined mainly to the *bheries* (man-made impoundments in coastal wetlands) of West Bengal, *gheris* in Odisha, *pokkali* (salt resistant deep water paddy) fields in Kerala, *khar* lands in Karnataka and *khazans* on the coasts of Goa. These systems have been sustaining production of 500 to 750 kg/ha/year with shrimp contributing 20 percent to 25 percent with no additional input, except that of trapping the naturally bred juvenile fish and shrimp seed during tidal influx (FAO, 2014).

The Indian Sundarbans located in the lower Gangetic region of the Indian Subcontinent at the apex of the Bay of Bengal (within latitude 21°13' N to 22°40' N and longitude 88°03' E to 89°07' E) covers approximately 2 069 sq km and offers a congenial environment in terms of salinity and other hydrological parameters for the growth and culture of a variety of fishes. In this coastal region, there are a large number of poor marine fishermen who primarily depend on the sea for their livelihoods. As the economic benefit of aquaculture is greater than that of traditional fishing and as there is a potentially suitable area of 0.21 million ha available for brackishwater aquaculture, there is a tendency for fishermen to shift from fishing to aquaculture.

Nevertheless, aquaculture has been a traditional practice in the State of West Bengal for centuries (Beveridge and Little, 2002). In this traditional method, low lying areas near the banks of saline water rivers and creeks are encircled by a peripheral dyke and tidal water is allowed to enter the impoundment along with natural seeds of various species of shrimps, crabs and fish. Water is retained with periodical exchanges during lunar cycles and the animals are allowed to grow utilizing natural food brought in through tidal water. In the process of tidal water exchange, some predatory and carnivorous fishes such as *Lates calcarifer*, *Megalops cyprinoides*, *Eleutheronema tetradactylum*, *Therapon jarbua*, *Glossogobius giuris* gain entry, resulting in low production (Biswas *et al.*, 2012). This traditional method of finfish and shrimp cultures, with some modification, still exists because of its simplicity and low operational cost. The traditional method is being gradually replaced by modern improved culture practices. Commercial shrimp farming started gaining roots only during the mid-eighties in India with a serious setback in 1995/96 because of outbreaks of viral diseases (Mehta, 2009). The present form of shrimp farming has become a high-risk venture and profitability is decreasing. The reasons behind decreasing profitability are an abnormal hike in the input cost and unpredictable market prices. In recent years, viewing the risks associated with shrimp farming and decreasing profitability, small-scale farmers strongly felt the need to diversify to secure stable incomes and sustainability.

Polyculture is potentially more sustainable than monoculture because of the utilization of waste products of one species by another (Petrell *et al.*, 1993; Chopin and Yarish, 1999). Shrimp polyculture represents an important alternative for solving and/or minimizing some of the problems that shrimp aquaculture has faced in the past two decades (environmental pollution, diseases and crop failures). Polyculture in its present form, although being environment friendly and most suitable for ecologically vulnerable areas like the Sundarbans, is characterized by low production resulting in low incomes. There is an urgent need to increase production for better incomes from unit area keeping in view the issue of sustainability. Modification of the traditional brackishwater polyculture is a logical choice when considering the expansion of aquaculture.

Several species from different trophic levels have the potential to be co-cultured with shrimp. A good knowledge of the species selected for polyculture and an adequately designed culture system are the most important points to consider when co-culturing shrimp with other species (Martínez-Porchas *et al.*, 2010). Locally available compatible species selection and standardization of stocking density of individual species being co-cultured is of immense importance. Aquafeed is a crucial input to improve production in any fish or shrimp farming system and aquafeed accounts for about 60 percent of production cost. Because brackishwater polyculture is a low-cost, low-input system, an adequately formulated low-cost feed is essential for successful polyculture with improved production.

To address these issues, the Central Institute of Brackishwater Aquaculture conducted a series of experiments in an indoor system, on-farm and in the farmers' ponds to standardize a brackishwater polyculture system. To make the system more economic and sustainable, a low-cost farm-made feed using locally available ingredients was developed and used in the polyculture system.

1. Sustainable intensification of aquaculture (SIA) practice (low-cost farm-made feed for improved production efficiency in a polyculture system)

Six selected species of brackishwater fishes at different stocking densities, *Liza parsia* (5 000/ha, average body weight (ABW): 0.5 g to 1.7 g), Liza tade (5 000/ha, ABW: 0.5 g to 1.8 g), *Mugil cephalus* (2 500/ha, ABW: 11.0 g to 50.0 g), *Scatophagus argus* (2 500/ha, ABW: 0.34 g to 10.0 g), *Mystus gulio* (30 000/ha, ABW: 0.53 g to 5.0 g) and *Penaeus monodon* (2 500/ha, ABW: 0.02 g to 0.45 g) were stocked in farmers' ponds. Fishes were fed at 2 percent to 10 percent of feed of total biomass. Water quality parameters were monitored periodically every month. Lime was applied in the pond at 140 kg/ha monthly. After 325 days of culture, the crop was harvested and *L. parsia, L. tade, M. cephalus, S. argus* and *M. gulio* attained ABW of 25.31 g to 57.35 g, 46.64 g to 110.09 g, 189.14 g to 300.15 g, 38.93 g to 180.44 g and 25.07 g to 180.44 g, respectively in three trials in triplicate in nine farmers' ponds. Partial harvesting of *P. monodon* was done five months after the start of culture and shrimp attained a body weight of 32.21 g to 55.0 g. Survival rates of *L. parsia, L. tade, M. cephalus, S. argus, M. gulio* and *P. monodon* were in the range of 72 percent to 75 percent, 75 percent to 79 percent, 70 percent to 82 percent, 76 percent to 90 percent, 65 percent to 86 percent and 56 percent to 65 percent, respectively in these three trials.The total productivity figures of 3 141, 3 855 and 4 764 kg/ha with low-cost farm-made feed were recorded for 1st, 2nd and 3rd trials, respectively against the productivity of 1 597 kg/ha in polyculture with conventional rice bran and mustard cake mash. Feed conversion ratio (FCR) of farm-made polyculture feed ranged from 0.88 to 1.36 (Table 1).

Table 1 Production performance of polyculture under different trials

	Polyculture with rice bran & mustard cake mash feed	Polyculture with farm made pellet feed		
		1st trial	2nd trial	3rd trial
Culture duration (days)	300	325	325	325
Productivity (kg/ha)	1 597	3 141.43	385 509	476 411
FCR	3.45	0.88	1.36	1.32
Survival (%)	–	75.60	70.53	75.61

Through various trials, low-cost (cost per kg of feed = Indian rupee INR25.32, USD0.41) farm-made feed with locally available ingredients (wheat flour, fishmeal, mustard oil cake, rice bran, sunflower cake, mung husk and vitamin mixture) was developed and used in the polyculture trials to reduce the cost of production. Substantial efforts have been made to develop this feed using unconventional ingredients after studying their inclusion level in candidate species by partially replacing the costliest ingredient, fishmeal. It was found that feed (CP – 29.77 percent) containing different unconventional ingredients (sunflower cake, mung husk) with 10 percent fishmeal performed at par with that of feed containing 22 percent fishmeal in respect to growth and FCR. Based on these observations, a feed formulation was developed containing unconventional feed ingredients and a low percentage of fishmeal (10 percent). The approximate composition of the developed low-cost polyculture feed is presented in Table 2.

Table 2 Approximate composition of low-cost polyculture feed

Constituents	%
Dry matter	96.02±0.11
Crude protein	29.77±0.06
Ether extract	5.00±0.03
Crude fibre	8.72±0.04
Organic matter	88.70±0.03
Acid insoluble ash	3.72±0.05
Nitrogen free extract	45.21±0.01

A series of experiments were conducted for evaluating the performance of developed feed in an indoor system, on-farm and in the farmers' ponds. The feed produced through this technology was field tested at farmers' ponds in a polyculture system with productivity upto 4 764 kg/ha and FCR of 1.32. This technology has been transferred to the farmers of the Sundarbans, West Bengal, India. To supplement their incomes from aquaculture, pond dykes were used for growing seasonal vegetables.

2. Process

2.1 Standardization of polyculture practices

Several experiments were conducted in an indoor system, on-farm and in the farmers' ponds to standardize a species combination in a polyculture system with indigenous brackishwater fish and shrimp species. Initially, productivity of 1.98 tonne/ha was achieved in polyculture of *P. monodon* (20 000/ha) and three non-carnivorous fishes, *L. parsia* (5 000/ha), *Chanos chanos* (5 000/ha) and *M. cephalus* (5 000/ha). Further refinement of the polyculture system was made with the introduction of available high valued species such as *M. gulio* and *S. argus,* which increased the production to 4 764 kg/ha, with low-cost farm-made feed.

2.2 Development of low-cost farm-made feed formulation for polyfarming: inclusion level of locally available ingredients

In order to develop a low-cost feed for polyculture (CIBA-LPF), experiments were conducted to determine the inclusion level of different protein rich unconventional ingredients such as mung (green gram) husk (MH), sunflower cake (SFC), deoiled karanja (Indian beech) cake (DOKC), mango seed kernel (MSK) in diets of the most popular species co-cultured in traditional brackishwater polyculture, *P. monodon* and *M. cephalus*. It was found that MH and SFC can be incorporated up to the 5 percent and 10 percent level in the diet of *P. monodon* and *M. cephalus*, respectively. DOKC can be incorporated at the 2.5 percent and 7.5 percent level in the diet of *P. monodon* and *M. cephalus*, respectively and MSK can be included at the 7.5 percent level in the diets of both species without affecting survival, growth and digestibility.

2.3 Steps followed for farm-made pellet feed preparation

To prepare farm-made pellet feed the following steps are carried out:

- grinding ingredients to uniform particle size and mixing;
- adding water to increase moisture content of the mash to 45 percent to 55 percent to produce good pellets;

- steam cooking in an idli cooker or in a big container at 100ºC for five to ten minutes;
- incorporating vitamin-mineral mixture;
- pelletizing: feed mash mixture was passed through a pellet machine (mincer) with 1 mm, 2 mm or 3 mm die depending on the size of the fish that is being fed. The pellet was cut into the required length with a knife during extrusion or broken into smaller lengths after drying;
- drying the moist pellets to a moisture content of ≤12 percent; and
- storing the dried and cooled pellets in bags or containers away from insects, rats or other pests and keeping out moisture.

2.4 Standardization of feeding frequency and mode of feed application

Based on the feeding experiments, it is suggested that low-cost pellet feed should be offered as supplementary feed at 2 percent to 10 percent body weight per day depending on the weight of the fish. The daily ration has to be distributed at three equal quantities in the morning (09.00 hours), afternoon (13.00 hours) and evening (17.00 hours) in trays. Total feed has to be offered in a feeding tray and the amount has to be given in two split doses at one-hour intervals (09.00 hours, 10.00 hours, 13.00 hours, 14.00 hours and 17.00 hours, 18:00 hours) to meet the requirements of various sizes of fish.

The polyculture technology with farm-made feed was disseminated among the existing farmers' cooperatives and as farmers got promising results, the beneficiaries requested the supply of feed from CIBA on a payment basis. Initially feed was supplied realizing only the production cost from CIBA experimental feed facility, but as more farmers got into farming, they set up their own feed production unit with a small-scale pulverizer and pelletizer and started producing feed as per their requirements. Now, the "CIBA-LPF" technology has been widely adopted by the brackishwater farmers of the Sundarbans, West Bengal.

3. Impact created

3.1 Enhancement of production and economic benefit

Production figures from brackishwater polyfarming with low-cost farm-made feed in the range of 3 141 kg/ha to 4 764 kg/ha in three trials in nine farmers' ponds were much higher than the production figures from generally practiced polyculture with conventional rice bran and mustard cake mash. Lower FCR of 0.88 to 1.36 using low-cost farm-made polyculture feed compared to 3.45 in the conventional feeding method indicates much better utilization efficiency, providing an economically and environmentally sustainable farming model. Economic analysis also revealed an excellent return on investment as summarized in Table 3. The polyculture practice has been demonstrated to 57 farmers in West Bengal and an area of about 30 ha has been brought under improved brackishwater polyculture practices with low-cost formulated feed.

3.2 Social impact

This polyculture activity has been widely adopted by small and marginal aquaculture farmers who could not adopt shrimp farming because of the high input costs and other risk factors. Adoption of polyculture using low-cost farm-made feed has improved the economic status of the farmers.

Table 3 Economics of polyculture for 1 ha area with low-cost farm-made feed

Parameters	Quantity	Rate in INR (USD)	Amount in INR (USD)
Bleaching powder	300 kg	25 (0.41)/kg	7 500 (123.00)
Lime	710.2 kg	10 (0.16)/kg	7 102 (113.6)
Pumping for water intake	127.41 hours	100 (1.61)/hour	12 741 (205.1)
Seed			74 984 (1 209.4)
Feed	4 660 kg	25.32 (0.41)/kg	117 991 (1 910.6)
Labour	179 man-days	260 (4.19)/man-days	46 540 (750.0)
Harvesting (netting and dewatering)			24 500 (395.2)
Marketing (transport)			16 597 (267.7)
Sub total			307 955 (4 974.6)
Interest on operational cost	11% for 11 months	12% annually	33 875 (546.4)
Total operational cost			341 830 (5 521.0)
Economic return from fish sale			633 090 (10 211.1)
Net profit			291 260 (4 690.1)
Benefit-cost ratio			1.85

3.3 Involvement of women

Polyculture practices are mostly a homestead activity. Therefore, as a domestic activity, women actively participate during the process of pond preparation, feed preparation and management, harvesting and selling of the produce to the local domestic market.

3.4 Environmental benefit

Polyculture is environment friendly, cost effective and is more sustainable than monoculture because of the utilization of waste products of one species by another. Shrimp polyculture represents an important alternative in solving and/or minimizing some of the problems that shrimp aquaculture has faced in the past two decades (environmental pollution, diseases and decreasing profitability). Several local fish species from diverse trophic levels have the potential to be co-cultured with shrimps and it reduces the use of commercial feed and hence protects the environment in a sustainable way.

4. Lessons learned

4.1 Successful experiences

Aquaculture farmers of coastal rural areas started preparing and using the farm-made feed using locally available ingredients. Production improvement of twofold to fourfold compared to the conventional fish culture system has been observed and farmers are showing keen interest in adopting polyculture with low-cost farm-made feed. Brackishwater farmers (57 of them) of West Bengal, India conducted polyculture of brackishwater fish and shrimp using CIBA technology. They prepared feed with a hand pelletizer/small pellet machine. Use of the farm-made feed in a polyculture system resulted in a net profit of INR143 611 (USD2 316.31) per hectare within a seven-month period with an impressive benefit-cost ratio of 1.81. Brackishwater polyculture using the CIBA developed farm-made feed "CIBA-LPF" has become popular and currently progressive farmers in West Bengal are undertaking polyculture using this feed. During the course of preparation of farm-made feed, farmers faced some problems of pulverizing the ingredients. The owner of a flour mill available in a nearby village does not always allow grinding of the feed ingredients. To cater to their need for farm-made feed, the farmers formed a fisherman's cooperative society and purchased a pulverizer with the financial help of the State Government. This society helps them in decision-making, adoption of improved technology and bulk purchase of locally available feed ingredients in the lean season resulting in a lowering of the production cost of feed. The operation cost of pulverizing is shared by the farmers and a further increase in the number of beneficiaries will further reduce the feed cost. This experience can be shared with countries such as Bangladesh and Myanmar that have similar environmental conditions for further expansion of improved brackishwater polyculture, keeping in mind the sustainability of present practice.

4.2 Gaps to fill

Exploration of other potential locally available cheap ingredients such as tapioca flour, mango seed kernel, deoiled karanja cake, tamarind seed flour, sesame oil cake for inclusion in farm-made polyculture feed to lower the production cost and better efficiency, need to be carried out. Development of specific feed formulation for target species combinations need to be carried out too. Farmers need up-to-date information on ingredient availability (sources and suppliers), costs and inclusion rates in formulations. Further research is needed to develop improved indigenous feed processing technology to achieve better digestibility. Research is also needed for further refinement of feeding management practices for brackishwater polyculture as a step towards increased sustainability through minimizing waste production. Optimum stocking density of different species in combination has to be standardized. The addition of potential compatible species depending on feeding ecology may also improve production and economic and environmental efficiency. Environmental consequences of brackishwater polyculture using low-cost farm-made feed should be studied and the formulation can be manipulated to make it more environment friendly. Feed formulation may be manipulated according to the needs of particular species combinations to increase output.

4.3 Potential for further improvement

As brackishwater polyculture with low-cost farm-made feed is a new initiative, there might be some drawbacks. Farmer-researcher coordination is necessary to get proper feedback for further improvement. As tiger shrimp is a valuable component in brackishwater polyculture, the addition of immuno-enhancers may be considered to reduce vulnerability of viral and bacterial diseases. As co-cultured species in polyculture feed at different trophic levels and have different feeding preferences, a combination of floating and sinking variants of feed may be considered for better production and waste recycling. Small-scale low investment feed mills can be established at strategic locations to make the feed available to the farmers. Proper extension services are necessary for dissemination of the technology. Improved ingredients such as fermented and/or ameliorated materials may be used to improve efficiency of the feed. Farmers should be trained about better management practices for brackishwater polyculture so that they can utilize aquafeed in the right way.

5. The way forward

Low-cost farm-made feed for scaling up brackishwater polyculture offers a vast scope and different strategies have to be implemented for its sustainable development. Among short-term strategies, enhancing an area under cultivation with an improved traditional system of farming, dissemination of technology for farm-made feed preparation among farmers, modification of feed formulation using potentially low-cost ingredients to reduce costs and enhance efficiency, extension services to train farmers on low-cost farm-made feed management are the way forward. The farmers can be grouped into societies or self-help groups to establish a small-scale feed plant with profit sharing and the cost of feed can be brought down to a level of INR20/kg (USD0.32) through the bulk purchase of ingredients.

Among long-term strategies, utilization of inland saline soils, development of organic polyfarming using low-cost fishmeal farm-made feed, adoption of cage polyculture of fishes and overcoming the constraints through participatory fisheries management, refinement of indigenous technical knowledge and encouraging entrepreneurship are the way forward. The main areas to be addressed to scale up brackishwater polyculture using farm-made low-cost feed as the most important factor are enumerated below.

1. development of a seed bank for candidate brackishwater species in different strategic locations – non-availability of desired fish seed in time is a major constraint for brackishwater polyculture and nursery rearing and establishment of a seed bank using low-cost farm-made feed may open another avenue for entrepreneurship development;
2. incorporation of crab as a component in polyculture and development of suitable feed formulation;
3. validation of low-cost farm-made feed in shrimp-tilapia polyculture, which is reported to be most efficient in waste recycling;
4. incorporation of marine/brackishwater algae as feed ingredient;
5. efforts towards complete replacement of fishmeal by enriched plant ingredients;
6. feasibility study and environmental impact assessment of production increment in brackishwater polyculture through low-cost farm-made feed;
7. standardization of optimum sustainable yield for different geographical locations;
8. provision of proper extension services on farm design and construction is of immense importance for sustainable development of brackishwater polyculture;
9. establishment of small laboratories for water and soil analysis at strategic locations is very much required for better culture management;
10. proper storage facilities for feed and harvested material and value addition are important factors to increase profitability and marketability;
11. farmers should be made aware of environmental issues related to aquaculture and of the superiority of low input brackishwater polyculture over semi-intensive monoculture from an environmental point of view;
12. efforts should be made to achieve "organic" status certification for traditional farming activity; and
13. development of local markets to ensure nutritional security objectives.

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Country Paper 6: Increased resilience and empowerment of small aquafarmers through cooperatives in China

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Abstract

In China, small-scale aquaculture farmers have weaknesses in marketing and pursuing economic development. There are obvious disadvantages in adopting new aquaculture standards, for example lack of power to negotiate a favourable price when purchasing inputs such as fish seed or commercial aquafeed, and lack of technical knowledge, marketing information and good facilities. These disadvantages have greatly discouraged the aquaculture farmers from engaging in sustainable development and pursuing profit. Fishery cooperatives were developed as an institutional mechanism to improve fish production standards and also the marketing of the fish produced. In terms of their managerial and social practices, the cooperatives have promoted sound environmental benefits, economic viability, farmers' resilience and the social acceptance of intensive/semi-intensive aquaculture while enhancing the productivity and improving resource use efficiency through large-scale practices.

Erhu, a famous town in Wuxi City, has a hundred years long tradition of black carp production. Its producers decided that black carp production could become a modern aquaculture industry. With the mission of "sharing risk, services and benefits", various black carp cooperatives began operating in 2006. The most famous and most successful, the Ganlu black carp cooperative, was established in 2007. The cooperatives' members enjoy common aquafeed distribution, a common drug supply, common technical training and guidance, and a common brand for their sales. The cooperatives have greatly lowered the production cost, improved the quality of management and marketing of black carp farming, as well as provided a better economic return to each farmer. Based on the experience of production organization in China, fishery cooperatives are a successful approach to empowering small aquafarmers and increasing their resilience. More and more fish farmers have subsequently established fishery cooperatives to improve their sustainability and reduce marketing risks.

Introduction

Before the 1980s, Chinese aquaculture production was organized around family-based business practices. Families viewed aquaculture as a way of making money and joined village fishery teams with this in mind. In these village fishery teams, members have to follow a production plan and fulfill the production target, however, they tend to be inefficient and often fail to meet the market demand (Ma, 2011). This form of organization has, nevertheless, promoted aquaculture and greatly improved the supply of aquaculture products and diversified the available consumer selection (Chen, 2009).

With the adoption of a market driven economy, more and more commercial inputs were adopted in aquaculture practices, such as commercial feed and seed inputs. Farmers had to buy fish seed and commercial feed, instead of producing them themselves. Marketing became a major bottleneck in making improvements in economic efficiency as family farmers have limited market information, and little negotiating power in pricing during purchasing and selling, mainly because of the small demand and limited supply available (Xu, 2014). To overcome the price negotiation constraints, and the small scale of land ownership, which is enforced under Chinese law, fishery cooperatives were seen as a tool to explore and enhance the power of aquaculture farmers (Ma, 2011). Aquaculture farmers elected representatives to represent them during negotiations with commercial aquafeed company and seed suppliers. In this case, the commercial aquafeed companies and suppliers agreed to give a discount for bulk procurement. Moreover, fishery cooperatives had access to technical knowledge and marketing information that they shared with their members (Hu *et al*., 2010). Thus the cooperatives helped farmers to meet the standard practices of sustainable aquaculture, improve infrastructure and adopt a code of conduct for quality control. This enabled the cooperatives to sell their products under their own brand and with a guaranteed high quality and high price.

The cooperatives played a core role in the process of gaining access to new knowledge and enhancing market oriented learning processes. A professional cooperative can undertake external marketing and promotion activities based on well-prepared concepts and strategies. It can learn about the changing market demand by having a wide network of external linkages with other organizations and institutions to receive information on market fluctuations. Furthermore, cooperatives have a very important function in distributing this information to members through a combination of market forecasts, internal campaigns, education and training programmes etc. This enables members to match the supply with the demand (Xu, 2014).

1. Practice of fishery cooperatives

Establishing a fishery cooperative is a collective approach for small-scale community-based aquaculture that is applied collectively to implement strategies in the value chain for pond fish farming so that farmers enhance their incomes through savings on inputs and better market prices for their produce.

1.1 Establishment of fishery cooperatives

Fishery cooperatives should be registered and officially recognized bodies set up by self-organized fishery or aquaculture farmers, brokers and related stakeholders. All members are involved in one or two sectors of aquaculture and marketing of the same commodity. They facilitate the day-to-day management of aquaculture from production to marketing with the following crucial roles: they guide member farmers towards sustainable fishing and aquaculture, in particular by collectively managing the activities of their members, helping them to match supplies with market demands, and supporting them in creating added value.

Today, more than 40 000 fishery cooperatives exist in China. To achieve the objectives of the markets, they take measures to channel the produce of their members, promote them through certification schemes, quality control systems, brand construction, geographical labels and so on. They may also promote vocational training, new technologies and work towards reducing the adverse environmental impact of the aquaculture activities of their members.

1.2 General conditions for aquaculture farmers to establish fishery cooperatives

In China, the current general development status of fishery cooperatives in China is as follows:

- fishery cooperatives are key players for reducing the market risk of fish farmers;

- more and more groups of fish farmers are coming together voluntarily to form a cooperative organization;
- the cooperatives promote scientific aquaculture management through combined bulk purchases to reduce cost, technology transfer and training in technology; and
- the cooperatives promote methods that encourage sustainable aquaculture during fish production, which helps to realize the government's management function; and

The original objectives of forming cooperatives remain unchanged and are: to improve the marketing of products; to provide market stability; and to guarantee a fair income for fishery products.

1.3 Development history of Ganlu black carp cooperatives

In the 1980s, Wuxi was a national model for high yield freshwater aquaculture in ponds. With the process of urbanization and the lake ecosystem reconstruction, a large area of pond fish culture was abandoned, and the aquaculture area declined. If aquaculture was to continue in some form, changes were clearly necessary. But in order to engage in sustainable aquaculture, farmers had to adopt practices that were economical, environment friendly and followed a modern style of organization (Hu *et al*., 2010).

Erhu town is the most famous place in Wuxi with a tradition of black carp production. There is nearly a hundred years of aquaculture history of black carp culture here. Modernizing black carp production was the beginning of the modern aquaculture industry in Jiangsu province. Six cooperatives were established initially (Table 1). Through the implementation of standardized production, science and technology management, industrial development, the production of Ganlu black carp has become popular among local households and the black carp has become a famous agricultural product brand of Jiangsu province. The cooperatives have played a prominent and exemplary role in promoting local fisheries synergies and raising local fishermen's incomes. Initially, with the progress of the fishery economy and the development of a market economy, the output and scale of individual farmers left them at a disadvantage with respect to the high prices of the commercial input supply companies and unable to meet the market demand. Various problems existed:

- the culture area for the individual members was usually 10 to 20 *mu*;
- because of their low standard of education and technical background, farmers were not willing to adopt the standardization of production requirements;
- the lack of technology transfer, and thus the low level of technology used, resulted in lower production efficiency;
- the promotion of new technology was rather difficult because of high investment cost;
- individual fish farmers were constrained because of lack of market information and advanced production technology;
- weak consciousness of quality standards and ability to manage market risk; and
- under these circumstances, black carp producers' cooperatives were established to mobilize and integrate the farmers' resources and thus to face the market as an industrial type organization.

Table 1 Development of fishery cooperatives in Erhu town, Wuxi city

Name of FC	Date of establishment	Official registration	No. of formal member farmers	No. of associated non-member farmers
Erhu fishery association	30 June 2006	no	85	300
Ganlu black carp cooperative	21 Dec 2007	yes	103	500
Dangkou aquaculture cooperative	9 Nov 2007	yes	101	200
Xuku cooperative	2 Feb 2008	yes	20	150
Songzhi cooperative	16 June 2008	yes	101	200
Huguang cooperative	1 May 2009	yes	100	150

Aquaculture is the main industry in Erhu town, and black carp is the main species for aquaculture. The brand of Ganlu was established in 2007. In 2014, the whole aquaculture area in the town was 300 ha, among which 153 ha was devoted to black carp. The total output of aquatic products was 5 316 tonnes and the output for black carp was 1 100 tonnes. The output value of aquatic products in the town was CNY123 million, and the fishery economy output value amounts to CNY378 million with the added value of CNY57 million.

2. Main Drivers

2.1 Government guidance and encouragement

Sustainable aquaculture development and improvement of farmers' incomes have been a main focus of government policy in recent years. Thus in order to promote modern aquaculture and ensure a profit for farmers, and realizing the conflicts between farmers and the market economy, the government has released policies on cooperatives and assigned fishery technical extension technicians to help with the establishment of cooperatives and registrations.

2.2 Successful model of agriculture cooperatives

In 2006, the national law on agriculture cooperatives was published. After that, there were over 0.9 million cooperatives registered in China (Kong and Zhan, 2014). Most of them belong to agriculture farmers, and many successful cooperatives have been reported. With the market driven economy, some fish farmers tried to establish cooperatives in place of traditional agriculture and aquaculture practices. The successful models of agriculture cooperatives provided positive examples for aquaculture operations.

2.3 Training, technology transfer and marketing

Most aquaculture farmers lack confidence in operating a business because of their lack of education and experiences. But they have a strong desire for their business to be sustainable. When organizing cooperatives, training and transfer of technology and sharing marketing information has contributed significantly to the success of business operations, which has attracted more and more farmers to join the cooperatives.

2.4 Leadership of the successful aquaculture farmers

Well-organized fishery cooperatives have professional and successful aquaculture farmers as group leaders who have leadership skills and are willing to serve other farmers in providing technical guidance for grow-out farming, good pond management, collective procurement of fish seed and feed, and marketing of their products. The member farmers enjoy receiving the technical guidance and assistance in value chain development as this improves their ability to manage risk.

3. Operational mechanism of the Ganlu Black Carp Cooperative

The Ganlu Black Carp Cooperative was set up in accordance with the law and regulations relating to farmers' cooperatives in China. The internal administration is composed of a members' congress as the highest authority supported by the Director and the Technical Supervisor. The Director has the overall responsibility for the management system. The management system is divided into two parts, namely the financial management system and the distribution system. The former has a set-up with a general ledger, a ledger, subsidiary accounts, account books etc. The latter system determines the rebate according to the turnover. Surplus profit is distributed to all the members each year as stipulated in the financial management system. The Ganlu Black Carp Cooperative was formed in December 2007 with registered capital of CNY224 000, of which CNY20 000 was contributed by the group head Mr Teng Guo Zhong, the contracted members contributed CNY2 000 per person, so the total of 112 shares amounted to CNY224 000.

The Ganlu Black Carp Cooperative is mainly engaged in aquatic products aquaculture and their marketing; procurement of aquafeed and seed; introduction and adoption of new technologies and fish varieties; aquaculture related technical training, information transfer and consulting services. There are a total of 3 500 *mu* aquaculture ponds (including 2 000 *mu* of environment friendly organic base). Under the cooperative, 1 000 *mu* of provincial standard demonstration ponds area of black carp, an aquaculture hospital, a farmer's field school for technical training, one aquatic products sales store and one fishery supplies distribution store. Under the mission of "sharing risk, services and benefits", the Ganlu Black Carp Cooperative is operating with the "cooperative + company + base + farmer" industrialized mode. During production, marketing, technical training of members, it maintains the keywords of "four unification + a guarantee".

The Ganlu Black Carp Cooperative of Wuxi was the pioneer in China for black carp farming (Hu *et al*. 2010) and has achieved considerable success. Black carp farming was estimated to be providing employment to over 1 000 men in the Ganlu black carp aquaculture cooperative. This cooperative has proved that gains in sustainability (especially environment and natural resources), production efficiency and social equity, environmental issues, hygiene, public health and rural infrastructure can be realized through this kind of aquaculture organization.

3.1 Common feed distribution

The feed for black carp in Ganlu is mainly natural animal feed such as snails and clams, together with corn, wheat and other grain feed and compound feed. After the cooperative was set up, some members of the cooperative were specially designated and responsible for procurement of snails and clams, corn, wheat and within the scope of the whole town. Six stations for distribution of snails and clams have been set up, which significantly solves the problem of the farmers having to purchase the snails. However, the cooperative signs regular contracts with fishery supplies distribution channels, namely Tongwei Aquafeed Group Co., Ltd. in Wuxi City and Evergreen Feed Co., Ltd. in Zhejiang Province, which ensures the common supply of compound feed for its members with the quality guaranteed. Common procurement not only reduces the aquafeed price (common bulk procurement can receive a 5 percent lower price), but also it ensures the quality of the black carp feed from the big commercial feed companies.

3.2 Common drug supply for fish disease prevention and treatment

The cooperative hired technical specialists to provide consultancy services for fish diseases diagnostics and treatment consultancy services for fish diseases in the aquaculture base. During the high disease incidence season (June to September), information brochures on disease prevention were handed out to farmers. Moreso, specialists guided members on site with respect to drug application in order to reduce the occurrence of fish diseases. The cooperative signed distribution agreements with Zhongshui Fishery Medicine Co., Ltd. in Wuxi, for quality fish medicine supply, and Fisheries Technology Extension Station in Changshu City, which assures that no illegal drugs and unqualified products enter into the aquaculture practices. Both of these companies have reputations for providing first class quality products/services.

3.3 Common technical training and technical guidance

In the past, the traditional decentralized individual farms did not follow any quality control regulations in black carp production. Although there were relevant technical specifications, there was still a lack of supervision in the aquaculture process. After the establishment of the cooperative it began undertaking measures that would enable it to perform as an effective and modern producer of aquaculture products. First, it hired fisheries experts as technical advisers from the Freshwater Fisheries Research Centre and the Fisheries Extension Station of Xishan District. The advisers conducted regular technical seminars, technical training for members and carried out technical guidance and provided consultancy services. At the end of 2012, more than 90 percent of the members of the cooperative achieved advanced training certificates issued by the Ministry of Agriculture of China. Various technical training seminars have been conducted to train more than 2 000 fish farmers and 100 brokers. Second, the management record system in aquaculture ponds during the whole production process was implemented – members established a record book for each pond, and kept a record of stocking, model, feeding and drug application. It not only played a role in production supervision, but also ensured the production of quality and safe black carp as food fish.

3.4 Common brand for sales products

The cooperative declared a national environment friendly aquaculture base and products. Black carp produced by its members use the common brand of "Ganlu" for package and sales. Ganlu Black Carp Cooperative also employed brokers in marketing. It has a team of 20 brokers to promote retail and wholesale sale of its products, mainly in Wuxi, Suzhou, Changshu and nearby markets. Usually, these products are grass carp, silver carp and bighead carp and other aquatic products with daily sales of 5 000 kg to 15 000 kg. The winter season is the time for harvesting black carp, which is a seasonal product. The annual sales of all kinds of aquatic products have reached 2 500 tonnes in total. The cooperative also signed contracts with various food companies and supermarkets for selling the branded aquatic products. The cooperative signed an agreement on quality control and a marketing agreement with its members. In this way, the sales of products have been standardized.

3.5 Ensure a stable income of members

The cooperative sells fish at a base price/minimum price (floor price is evaluated in accordance with the calculation of minimum benefit of 3 000 yuan per *mu*), the price for grass carp and silver carp is 0.2 yuan higher than the market price of similar products per kg, and it is 0.1 yuan per kg higher for black carp. Special vehicles for fish transportation are arranged by the cooperative and distributed uniformly. Therefore, members only need to concentrate on better management of fish production. The cost and benefit in production performance is reviewed in Table 2. To ensure each member shares the risk and the aquaculture business runs smoothly, the cooperative provides an all-round service to its members. When its members report a lack of funding, the cooperative provides a guarantee for production inputs procurement. Farmers can, therefore, take aquafeed or fish seed in advance and pay back after harvest of crop production at the end of the year.

Table 2 Cost-benefit analysis of black carp aquaculture of a cooperative member (with pond area of 0.73 ha)

	Species	Amount (500 g)	Unit price (Yuan)	Total amount (Yuan)
Input	Black carp (large size fingerling)	5 000	8	40 000
	Black carp (fingerling of two years)	1 000	12	12 000
	Black carp (fingerling)	400	10	4 000
	Grass carp (large size fingerling)	900	4.5	4 050
	Grass carp (fingerling of two years)	1 000	5	5 000
	Grass carp (fingerling)	150	6	900
	Crucian carp (large size fingerling)	600	4	2 400
	Crucian carp (fingerling)	30	4	120
	Chinese Bream (large size fingerling)	500	4	2 000
	Silver carp (large size fingerling)	400	2	800
	Big head carp (large size fingerling)	220	2.5	550
	Snails	1 500 bucket	30	45 000
	Compound feed	5 tonnes	3 200	16 000
	Corn	30 000	0.75	22 500
	Rent	11 *mu* (0.73 hm^2)	350	3 850
	Drugs and electricity			2 000
	Labor	1	1 000	11 000
	Subtotal			172 170
Output	Black carp (commercial size)	12 000	10-11	120 000
	Black carp (large size fingerling)	1 600	8.5	13 600
	Black carp (fingerling of two years)	3 000	8	24 000
	Other commercial fish			40 000
	Grass carp (large size fingerling)	900	4.5	4 050
	Grass carp (fingerling of two years)	1 500	5	7 500
	Crucian carp (large size fingerling)	400	4	1 600
	Subtotal			210 750
	Net income			38 580
	Profit per *mu*			3 500

Note: Large size fingerling means the two to three years old fingerling that is still under marketable size. The black carp and grass carp usually take at least four years to reach marketable size, whereas silver carp, Chinese bream and crucian carp usually take two to three years to reach marketable size in the downstream part of Yangtze River. The feed for black carp is a combination of live food, supplementary feed and commercial pellet feed. Live food is usually benthos especially snails. Therefore snails are the main feed in their fast-growing season whereas some supplementary feed such as corn and soybean cake is also used in other seasons. Other commercial fish include grass carp, crucian carp, Chinese bream, silver carp and big head carp.

4. Impact of the Ganlu Black Carp Cooperative

The Ganlu Black Carp Cooperative has ensured the quality of its products, started brand construction, and promoted the use of advanced technology. As a result it has increased its output, profits, and the well being of its members. The positive impacts are as follows:

4.1 Improved production efficiency and food safety

In order to guide the sustainable aquaculture development, supported by the local government and related departments, the intensive aquaculture model was promoted to improve production efficiency. To ensure food safety and reduce management risks, a fish hospital was established to provide a high quality diagnostic service. A water quality and fish diseases examination room was established in Songzhi village aquatic base and is equipped with electric microscope and long distance video diagnostic system. Member farmers can receive good service in water quality assessment and fish disease monitoring.

4.2 Demonstration and extension of new technology and new varieties

The cooperative has strictly implemented a standard code of production for environment friendly aquaculture. In recent years, the polyculture technique of black carp with soft-shelled turtle, which has high yield and greater profit, has been popularized among the cooperative members. A digital and intelligent aquaculture management platform has been applied to diagnose fish disease, monitor water quality online using remote control. It has also enabled integrated brand identification. "Taihu No.1", a hybrid freshwater prawn, has also been introduced into the polyculture system. At present, there is a 400 *mu* provincial freshwater prawn seed farm that was established and is managed by the Ganlu black carp cooperative.

4.3 Marketing benefits: brand construction and expansion of sales channels

The brand "Ganlu black carp" that was registered as a trademark and a geographical indication was issued by the National Trademark Office in 2008. The brand has been ranked as an outstanding trademark of Wuxi City, as well as an outstanding trademark in Jiangsu province. It helps consumers to identify high quality black carp and guarantees its safety as food. To improve its marketing strategy, the cooperative tried many ways of product promotion, such as inviting the news media to make feature stories and TV programmes. It also opened up an e-commerce platform with modern logistics, a direct sales shop in the city and other marketing measures. These promotions helped to extend the black carp market all over the country.

4.4 Employment creation and gender equity

The cooperative also provided some services to interested farmers in the region and as a result more than 200 households joined the Ganlu Black Carp Cooperative from the local area and the surrounding areas. After several years of hard work, the cooperative has been rated as a top demonstration cooperative of Wuxi City and Jiangsu Province. In 2012, it became a "National model fishery cooperative". Songzhi aquaculture base, which is under the administration of Ganlu Black Carp Cooperative, won the "National advanced agricultural village" title, and was named a sustainable aquaculture demonstration farm by the Ministry of Agriculture, a modern agricultural demonstration base of Jiangsu province, and a standardized black carp farm of Jiangsu province. The farmers not only enjoyed the black carp farming and the service of fish marketing, but also increased benefits year after year. The farmer's profit was increased from CNY2 500 per *mu* in 2007 to more than CNY5 000 in 2014. The total value of fish output from 3 500 *mu* pond area run by the cooperative has reached CNY90 million, and a fisheries added value of CNY20 million. The cooperative has not only created hundreds of jobs, but has also achieved gender equity. The women fish farmers undertake jobs of feeding, cleaning and other management work.

5. Lessons learned from the Ganlu Black Carp Cooperative and other cooperatives

5.1 Successful experiences

- The cooperatives have administrative and financial resources, which gives them a professional and business-oriented service and a common organization both in terms of management and market development.
- All members support the aims of sustainable aquaculture development and the pursuit of high profit, based on production efficiency, the exchange of information, and economical operations that ensure the benefits for their members.
- The cooperatives have acquired high strategic capabilities as they have real professional and dynamic leadership.
- The cooperatives receive guidance from the government for optimum operating environment, better management and democratic organization. In this respect they play an important role in the farmers' increase in resilience and empowerment.

5.2 Gaps to fill

- There are different types of cooperatives in fisheries; they were created to deal with challenges at different times and in different places. The successful running of cooperatives requires the integration of knowledge and the modification of performance over time and in different situations.
- Talented and professional cooperative leadership is the key to the success of fishery cooperatives. The leadership should have broad knowledge of aquaculture and marketing management.
- Some of the cooperatives have to be upgraded to professional level and abilities, according to the change of members' expectations and the market demand.

5.3 Potential for further improvement

The future development of fishery cooperatives has two aspects: one is to ensure the sustainability of aquaculture and another to raise the farmers' incomes. Cooperatives have to expand the scope of participation of local fish farmers. Based mainly on black carp farming households, the cooperatives will also have to expand their influence among local aquaculture farmers and among those in the surrounding area. Cooperatives also have to expand the scale of operation. The cooperatives have tried to increase their capital investment and tried to reduce production costs and increase production efficiency. There is still a gap between the expectations of member farmers and the achievement of their goals in practice.

6. The way forward

- Within the last 20 years, aquaculture has become a highly professional business activity. Modern aquaculture development requires farmers to master or have access to specific skills related to a large variety of fast-developing technologies, which require the continuous updating of knowledge (Deng, 2014). Chinese fish farmers have been efficient at updating technology and utilizing new types of equipment in order to improve technical efficiency and productivity under the guidance of professional fishery cooperatives. These results are most notably achieved through a continuous process of establishing professional fishery cooperatives. Many fishery cooperatives have developed into modern, efficient organizations that influence the whole region in terms of sustainable aquaculture industry development.

- With regard to marketing activities, it is worth noting that initiatives and strategies at the national level are almost entirely absent from government activities. The government is oriented towards the policy area, and the national academic associations do not undertake any promotional activities, market analysis or strategy formulation. The processors' association undertakes some market support for the processors but there is a need for upgrading and coordinating strategic market action jointly with fish farmers at both the national and the regional level. The decentralized small-scale fish farmers lack the capabilities to have a broad understanding of the market and its fluctuations (Yang, *et al*. 2011). Thus, in the future it will be necessary to upgrade skills and qualifications by professionalizing fishery cooperatives at the marketing level.
- Fishery cooperatives should be capable of carrying out fisheries management tasks. Three important things are required:
  - financial resources to take over responsibility for management procedures;
  - professional skills in the administrative staff to formulate and promote the strategies; and
  - capability to manage variations in external conditions and the market.
- Future prospects for scaling up and dissemination of cooperatives should be conducted both in the country and in the region. Better practical guidelines for improvement of technical efficiency, disease control and polyculture should be elaborated. The organic aquaculture standard should also be promoted according to the market demand. The future market driven aquaculture products will therefore depend on the harmonization of production standards and consumers' expectations. Professional cooperatives are going to play a leading role in linking the small-scale fish farmers with the diverse and robust market through communicating the advantages of sustainable aquaculture products.

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Country Paper 7: Development of bivalve farming as a source of income generation for women's self-help groups in coastal India

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Abstract

The existing technologies of mussel and oyster farming were converted into an income-generating activity for coastal fishers, particularly for women's self-help groups. As a result of a concerted approach, coupled with novel extension techniques, commercial mussel and oyster farming became established in the States of India, Kerala and susequently in Karnataka. Production in 2009 was over 20 000 tonnes making India one of the top ten bivalve farming countries in Asia.

Innovations in these bivalve farming technologies simplified them, which resulted in an increase in profitability and made them attractive to farmers. During this process, the entire gamut of bivalve farming operations such as site identification, seed and spatfall calendars, remote setting, mechanization in seeding and harvesting, quality and depuration protocols, ready-to-eat and ready-to-cook products, organic farming protocols and environmental impact assessments were worked out. The success in commercializing the technologies was mainly a result of a unique synergy that was actively pursued and developed by technology developers, promoters, and credit advancers. This development scenario can serve as a role model for other states and developing nations where a similar hydrological, social, and market environment exists.

Introduction

Bivalves have been traditionally a subsistence food for the coastal people in the west coast maritime states of India from time immemorial. Typically, harvests from the wild, mainly mussels, amount to nearly 15 000 tonnes per year. The Central Marine Fisheries Research Institute (CMFRI) developed simple techniques for farming the green mussel (*Perna viridis*) and the backwater oyster (*Crassostrea madrasensis*) during 1980 to 1990, modifying the rope culture system for mussels and the rack and ren method for oysters. And for more than one decade these technologies remained dormant and were never commercialized in spite of several training programmes conducted by the Institute. At the same time, many Asian countries utilized their water resources for bivalve farming and increased their production making substantial contributions to global aquaculture production.

Bivalves, especially mussels and oysters, are considered nutritionally rich health food and form an important candidate species for sustainable aquaculture globally. We present here a success story of developing an aquaculture practice, bivalve farming, implemented in the Southwestern States of Kerala and Karnataka that was able to:

- increase the aquaculture/seafood production on a sustainable basis;
- provide employment opportunities to coastal women, youth and the elderly;
- utilize the underutilized coastal backwaters for aquaculture effectively;

- promote entrepreneurship among women as aquaculture managers; and
- develop a series of ancillary industries in the coastal villages of Kerala to support aquaculture.

Mussel and oyster farming is simple, sustainable and an easy to adopt aquaculture practice by coastal communities without a high investment in feed. However, the initial transfer of technology (TOT) programmes did not succeed. This situation prompted CMFRI to establish an inter-disciplinary approach to disseminate the developed technologies. A critical examination of the technologies revealed that there are four disciplines that control the success of the technologies:

- environmental science for identifying unpolluted, biologically suitable farming sites;
- bivalve biology for determining seed collection and harvest timings;
- upgraded mariculture technologies for improving profit margins and for ease of operations; and
- transfer of technology involving demonstrations with farmers.

Work on these aspects began from 1996 onwards in a project mode. Initially, these projects were funded by the institute, and later, the institute's scientists were able to win considerable funding support from external agencies such as the National Agriculture Technology Project (NATP), the National Agriculture Innovation Project (NAIP) (both Indian Council of Agriculture Research (ICAR)/World Bank), the AP Cess Fund (ICAR) and Sweden's International Foundation for Science (IFS). As a result of this concerted approach, coupled with novel extension techniques, commercial mussel and oyster farming became established in the State of Kerala, and very recently in Karnataka. Through the efforts of CMFRI and support from the state fisheries departments and local governing bodies bivalve farming is an established practice in the estuaries of eight out of the nine coastal districts in Kerala (the eight districts are Kasargod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha and Kollam). With this success, very recently, the farmers have taken up bivalve farming in the neighbouring State of Karnataka also. During 2009 the bivalve production reached nearly 20 000 tonnes with India figuring among the top ten bivalve farming countries in Asia. Current production stands at 14 805 tonnes.

1. Sustainable intensification of bivalve mariculture practice – sub-components

1.1 Identification and continuous monitoring of quality of farming sites

Sites (both in the sea and backwaters) conducive for mussel and oyster farming in Kerala and Karnataka were identified through planned hydrographic surveys in the major estuarine, backwater and protected sea areas of the state. This information was disseminated in a comprehensive form (as project development reports) to the line departments such as the Kerala State Fisheries Department and other aquaculture development agencies in the state (Agency for Development of Aquaculture in Kerala-ADAK, Brackishwater Fish Farmers Development Agency-BFFDA etc.).

For the three major bivalve farming areas in the state, viz., Padanna Backwaters (in Kasargod for mussels); Sathar Island (in Ernakulam for mussels and oysters) and Dalawapuram (in Kollam for mussels and oysters), site monitoring in accordance with European Union criteria for water quality, microbes and pollutants is being done. As a result of this, a time series database on 14 hydrographic parameters is available. This reaffirms the fact that bivalve farming is done in areas where the product is safe for human consumption. Strict monitoring of the microbial load, biotoxins (algal blooms) and heavy metal pollution is also done to ensure food safety standards are met.

Oysters are one of the most important edible bivalve molluscs commercially farmed in Ashtamudi Lake. Oysters are filter-feeding animals that can filter large volumes of water for food and thus concentrate a microbial load more than tenfold in the growing environment. Oysters and oyster growing waters were sampled over a one-year period from July 2012 to June 2013 for analysis of total coliforms (TC), faecal coliforms (FC), *E. coli*, faecal *Streptococci* and total plate counts (TPC). *E. coli* MPN values in oyster growing waters were below the threshold limits set by the United States Food and Drug Administration (USFDA) and the European Union during the months of December, January, February, March and April. Seasonally, the highest MPN values for *E. coli* were obtained during the monsoon season. This trend gradually decreased during the post-monsoon and pre-monsoon periods. The rate of bio-accumulation of *E. coli* significantly correlated ($p < 0.01$) with faecal coliform content in the water, and in turn showed significant ($p < 0.01$) seasonal variations. Similarly, *E. coli* displayed a significant ($p < 0.01$) variation in accumulation during different seasons. A strong negative correlation ($R^2 = -0.70$, $p < 0.05$) between temperature and *E. coli* numbers in oysters was observed, whereas rainfall and *E. coli* were positively correlated ($R^2 = 0.695$, $p < 0.05$). Correlations between salinity, pH and faecal coliforms were not significant ($p > 0.05$).

1.2 Mussel seed calendar for Kerala and Karnataka States with season and abundance densities

The research team scientists conducted planned surveys to collect information on areas and timing suitable for seed collection from nature. The results of the surveys were published as a seed calendar for use by farmers. As seed is collected from the wild, low input costs were incurred for seed procurement and this contributed to the success of the technology. The seed calendar provided necessary information to farmers on when, where and how seeds can be collected.

1.3 Oyster spatfall seasons and protocols for setting rens

The oyster farming method is also dependent on the collection of seeds from nature. Here seed collectors (rens with stringed oyster shells) need to be placed in the water at precisely the time when larvae are available. This phenomenon shows wide interregional and interannual variability and therefore is constantly reassessed and frequent advisories are provided to farmers. This helped farmers and their family members to prepare the rens and place them at the right time in all the farming sites. This scientific planning has helped the farmers to get maximum profit because of the high settlement rate of oyster spat.

1.4 Protocol for remote setting of oyster larvae produced in hatcheries

For widespread adoption of oyster farming, natural seed availability should not be a constraint. Hence team scientists devised new remote setting techniques for hatchery produced oyster seeds, enabling farmers to reduce their dependence on natural seed. Briefly, the technique involves production of larvae in the hatchery, transporting it to the farmer's site and setting the larvae at the site. One remote set unit is functioning close to the Sathar Island oyster farming cluster for which seeds were supplied from the Narakkal Oyster Hatchery of CMFRI. Members of one self-help group are now proficient in rearing of larvae, feed preparation and setting the larvae on "cultch" material.

1.5 New mussel seeding technique in pre-stitched tubes

In mussel farming, the relatively high investment costs for polyethylene ropes and operating costs for transplanting mussel seeds can be reduced through the use of new seeding techniques. New methods were attempted by transplanting mussel seed to 12 mm diameter polyethylene ropes on which biodegradable cotton net was wrapped and stitched together (control) to 12 mm frilled polyethylene rope with white fully degradable tubing socks (FuW) and grey semi-degradable synthetic tubing socks (FuG) and to 5 cm broad flexible plastic strips (FPS) kept inside pre-stitched biodegradable cotton nets. The economic analysis indicated that the use of FPS together with pre-stitched biodegradable cotton nets reduced the investment costs by 34 percent and increased the rate of return by 48 percent over that of the control.

1.6 Reducing input costs and increasing profitability in mussel and oyster farming

Several experiments were carried out to reduce input costs and increase the profitability of mussel and oyster farming. Some of the successful refinements were: a) use of concrete-filled PVC poles instead of bamboo poles in the rack farm; b) use of flexible plastic strips instead of nylon ropes for mussel seeding; c) use of bamboo strips for single oyster farming; and d) integrated culture of finfish (*Etroplus suratensis*) in cages in bivalve rack farms.

1.7 Development of a semi-automatic mussel seeding machine

Semi-automation was introduced into the process of seeding mussels for mussel farming by the design and development of a mussel seeder. The seeder, which has an estimated cost of INR2 500 (USD42), was successfully field tested and demonstrated to mussel farmers in Kerala. The main advantage of the seeder is reduction in time consumed for seeding and thereby resulting in increased efficiency and lowering of labour costs and physical strain during the process.

1.8 Design and development of mussel harvester

Though mussels are relatively simple to culture, harvesting mussels from the ropes is a tedious and energy and time demanding process. To separate mussels from the rope, the concept of a semi-automatic de-clumping machine was developed and fabricated. The machine consists of a metallic drum and circular cutting shield through which the mussels are separated from the ropes. This simple device helps in easy harvesting and maintaining hygiene.

1.9 Depuration protocols for mussels and oysters for ensuring quality

Bivalves are filter feeders. During this process they accumulate all suspended biological materials including harmful micro-organisms. Before the product reaches the market, these materials have to be removed from their gut. Simple depuration can be achieved by starving the bivalves in clean and filtered seawater/brackish water for a certain period of time. More effective depuration can be achieved by using disinfected (chlorinated or ozonized) water in the depuration process.

Under the National Agricultural Technology Project (NATP) World Bank funded scheme, designs were developed for small and large depuration units, the latter functioning as a common depuration unit for small-scale farmers in a village and submitted to the Kerala State Fisheries Department and the Kerala State Co-operative Federation for Fisheries Development Ltd. (Matsyafed). The Kerala State Fisheries Department provided funds to farmers for establishing small depuration units with a high subsidy component as a part of TEAP (Tsunami Emergency Assistance Programme).

1.10 Development of a common depuration unit in the village

A common depuration facility was set up in Sathar Island using NAIP funds. The unit has specially designed tanks with slope, inlets and outlets. The water is treated by passing it through cartridge filters and UV filters. The model depuration plant aims to supply quality oysters to the public and establish an ancillary business of purifying oysters. Such oysters now command a premium price in the market thereby increasing the profit margin for the farmers. The common depuration unit (capacity approximately 1 tonne per day) is used by nearly 35 percent of farmers from two villages. Moreover, this model of clam depuration has been taken up by an NGO.

The efficiency of depuration of the Indian backwater oyster (*Crassostrea madrasensis*) using the fill and draw method (static method) with high-loading density was evaluated. The oysters located in trays on the surface and on the bottom were compared for microbial loads. The results showed that in winter monsoon-sampled non-depurated oysters, the most probable number of fecal coliforms and *Escherichia coli* were greater than the limits according to NSSP and European Union regulations. The surface held oysters took 24 hours to reduce the coliforms and *E. coli* levels to below safe limits whereas for bottom held oysters it took 48 hours. The species *Salmonella* was never detected in the oysters sampled, whereas *Vibrio* spp. was present in the non-depurated oysters and was eliminated completely after eight hours of depuration. Variation in depuration of total coliforms, fecal coliforms, *E. coli*, total plate count, and fecal streptococci in oysters was significant ($P < 0.05$) between surface and bottom oysters. The study results recommend a loading density of two oysters/L water stacked in one layer as the optimum loading density for commercial depuration completed within 24 hours.

1.11 Value chain to meet quality standards of live oyster consumption

Under the NAIP scheme, the production to consumption value chain for oysters was the main thrust, and high-value live oysters were a special focus in order to improve the incomes of women's self-help groups (SHGs). A major lacuna in this lucrative and emerging enterprise is the lack of consumer confidence in the quality of live oysters, particularly the purity of oysters with respect to micro-organisms. Accordingly, the CMFRI team designed and developed an ultra-pure oyster depuration display unit (DDU). With the availability of this unit and organization of special training programmes for chefs, several high-end hotels such as Casino Group of Hotels (CGH Earth), Taj Malabar, Gateway Residency (Kochi) and Taj Mumbai have started procuring and serving live oysters to their guests. As a result of this, a substantial increase in incomes of farmers became evident as the unit price of live oysters increased fifteenfold, from Rs.1 to Rs.15/oyster (USD0.25).

1.12 Design and development protocol for transport of live oysters

The survival of the tropical edible oyster (*Crassostrea madrasensis*) was examined under the condition of ice-storage in a rectangular thermocol-transport box for a period of 48 hours. A total of 100 two-year old farmed oysters were used for the experimental transportation. Inside the box, all oysters were arranged in four layers covered with wet-jute bags and lined on the top and bottom with ice. Surface and bottom temperature of the transport box varied from 9.7°C to 25.2°C and 9.7°C to 28.4°C respectively during the 48 hours exposure. The patterns of changing temperature at both surface and bottom were found to be different. Recoveries of the oysters every two hours till 48 hours were monitored by taking random samples from the box. All the oysters recovered within 1 hour of being placed back into seawater and there was close to 100 percent recovery within two hours. Survival was more than 90 percent after eight days of the experiment.

1.13 Design and development of an oyster steamer for hygienic processing

It is tough to retrieve oyster meat from its shell and heat shucking is often resorted to for this. However, this results in considerable loss of weight (nearly 55 percent) and consequently a loss of incomes for the farmers. In a baseline survey conducted to understand the problems of the farmers, it was evident that more than 65 percent of the expenses are incurred for heat shucking of oysters. Moreover, the farmers complained about the physical stress that they have to face if oysters have to be heat shucked using conventional heating systems. To circumvent this problem, the CMFRI team scientists designed and fabricated an oyster steamer together with a steam generator in 2010. This ensured that weight loss because of heat was reduced to 35 percent. This also ensured a quality product for further value added processing.

During 2011, almost 100 percent of the farmed oysters from Sathar Island were heat shucked using this steamer after being depurated, thus ensuring that the product is ultra pure. The qualities of the oysters were also checked microbiologically before marketing. This technology (under patent) has also been adopted by clam processors for depuration of wild-caught clams.

1.14 Muziris brand oyster ready-to-eat and ready-to-cook products

Under the NAIP scheme, which involved collaboration between CMFRI and the National Institute of Post Harvest Technology and Training (NIFPHATT), ready-to-cook oyster individual quick freezing (IQF) products in multilayered pouches and ready-to-eat oyster curries, pickles and cold-smoked oysters in cans were developed. These products are available to the public through NIFPHATT's fish stall and selected supermarkets in Kochi under the brand name Muziris. The team has taken the initiative to train members of the women's SHG in production of these value-added products. Now, the oyster farmers themselves can manufacture Muziris brand products for the market.

1.15 Organic farming protocols for mussels and oysters

Organic farming is based on holistic production management systems that promote and enhance ecosystem health, including biodiversity, biological cycles and biological activity. Molluscan shellfish aquaculture meets each of these criteria, and in fact, is arguably organic by default. Bivalve molluscs are not fed so there are no nutrients being added to the marine environment. They are biofilters that feed on phytoplankton that occurs naturally in the water. This biofiltering activity has the beneficial secondary effect of taking up nutrients and purifying the water column, thereby enhancing ecosystem health. The standards limited to production, processing and certification of aquaculture under the National Programme for Organic Production (NPOP) have been set for bivalves (mussels and oysters) through the collaboration of CMFRI and the Agriculture and Processed Food Products Export Development Authority (APEDA) in 2011.

1.16 Framework for mariculture water lease policy in India

In India, semi-intensive farming of shrimps, farming of green mussels and oysters, fattening of lobsters and crabs, finfish farming, seaweed farming, semi-culture of clams have increased aquaculture production in coastal ecosystems. In spite of these fast paced developments policy support to govern the mariculture development in a sustainable manner has not been forthcoming in the country. One of the major impediments in the development of mariculture in open access waterbodies is the lack of protection of the farm structures. A framework policy has been developed as a guide for government agencies to frame laws to govern mariculture in open access waterbodies.

1.17 Environmental Impact Assessment (EIA) of oyster farming

The impacts of oyster farming in estuaries and backwaters on benthic faunal assemblages and hydrography were studied. There were no significant differences in faunal densities in the benthos in the farm site and in a control reference site. The differences in univariate diversity indices in the farmed and control sites were not significantly different, and therefore, no negative impacts because of short-term farming of oysters in backwaters were observed.

2. The process

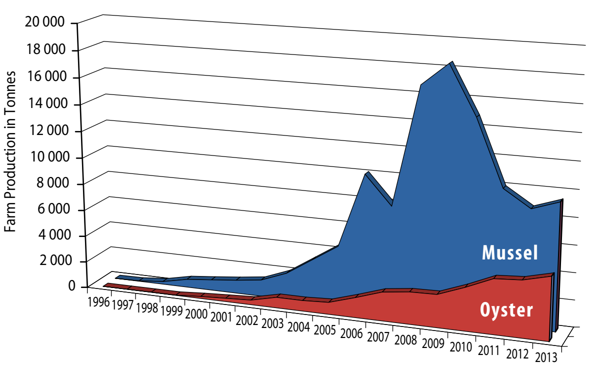
The successful transfer of technology for mussel and oyster farming in Kerala State resulted in a new model by which small-scale fishers, particularly women, could adopt an unconventional farming practice. After the sites were identified, the team scientists put up demonstration farms in close association with a newly formed SHG. Subsequently, the economic profile of this system was generated. The team then prepared a project report for mussels and oysters separately including sites suitable for farming, the season for farming, details of seed availability, implements for farming, farm maintenance and harvesting methods and marketing channels.

However, financing support is critical for large-scale uptake of farming especially when vulnerable components of society are involved. To make bivalve farming a means of enhancing benefits to farmers, especially women, on the basis of a proposal and project report a loan and subsidy package was developed with Kerala State Fisheries Department and also with its subsidiary aquaculture organizations such as the Agency for the Development of Aquaculture (ADAK) and the Brackish Water Fish Farmers Development Agency (BFFDA). These development agencies have implemented a financial assistance package for SHGs that will provide a financial impetus to this farming. Simultaneously, the team also got the project proposal approved by the National Bank for Agriculture and Rural Development (NABARD) for bank refinancing, thus enabling local cooperative banks such as the North Malabar Gramin Bank (NMGB) and village panchayats to offer loans to SHGs for large-scale uptake in other maritime states of India.

3. The impacts

3.1 Technology adoption and increased seafood production

As a direct effect of the TOT efforts by the CMFRI team, the farmed production of bivalves has increased from 2 tonnes in 1997 to 19 882 tonnes in 2009 making the nation one of the top ten Asian countries in farmed bivalve production. In recent times the production has declined to 14 085 tonnes because of issues of overcapacity in mussel farms. Whereas the production of farmed mussels has boomed from 2004 and then reduced, the growth in production in oyster farming has been slow and steady. This difference is mainly because of the differential popularity of the commodities and the relative ease in post-harvest management of mussels. The growth in the number of farmers (now more than 7 000) is also shown below (see Figures 1a and 1b). A recent development is the spread of mussel farming technology to Karnataka State, where the production increased fourfold from 7.5 tonnes in 2013 to 29 tonnes during 2014 from 29 farms.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Oyster	2	6	12	14	150	250	350	800	800	900	1500	2150	2400	2450	3200	4068	4202	4700
Mussel	2	27	200	609	800	1000	1250	2000	3250	4500	10060	7894	16789	18432	14817	9956	8703	9385

Figure 1a Growth in bivalve farming: production (tonnes)

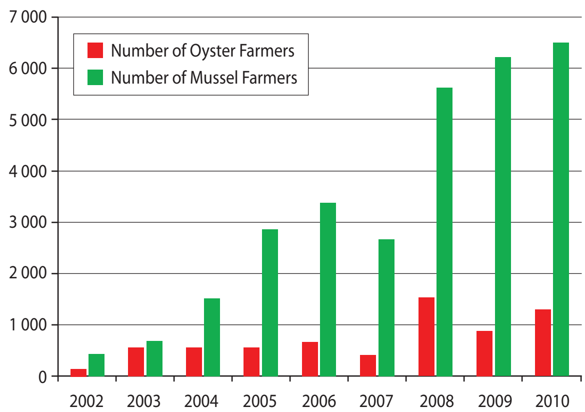


Figure 1b Growth in bivalve farming: number of farmers

3.2 Impact on rural employment: self-employment and creation of employment opportunities

Widespread awareness of the technology prompted many villagers to adopt the technology. Detailed study of the technology adoption in the year 2006 has shown that there are three types of farm ownerships viz., individual ownership, family ownership, and ownership by SHGs. The adoption curves are such that there were only a few adopters initially followed by an increasing rate of adoption in the subsequent years because of the demonstration effect. The study indicated there is a deep-rooted "risk aversion" attitude widely prevalent among technology adopters and we can confidently say that demonstrations and success stories in the villages can to a large extent motivate people to adopt new technologies.

3.3 Development of part-time employment opportunities in villages

- During the farming season the seeding is done on the banks of the estuary in front of farmer households. Typically it was found that an average farmer employs about three extra labourers and the SHGs also hire about <u>18 to 25 extra women</u> to seed the ropes.
- Seeding is a popular activity among village women. It was estimated that during the 2005-2006 season, 12 627 labour days were created for seeding mussels. Women get a payment of Rs.50 (~USD1) per day for seeding and at this rate it is estimated that labour worth Rs.630 000 (USD1 700) was generated in the mussel farming areas during the 2005-2006 period.
- Age could not be significantly related to technology adoption, but education and occupation of the respondents significantly ($P<0.05$) influenced the technology adoption process. There is immense scope to spread the technologies in other regions where more coastal people can get direct employment.

3.4 Women's empowerment through mussel farming

The biggest outcome of the growth of mussel farming in Kerala was the empowerment of women with 87 percent of the SHG farms owned by women. It is well known that women represent about 70 percent of the poor and there are gender inequalities. Farming of marine mussels has been found to be a women-friendly technology in Kerala. The technology was chosen by the women's self-help groups (SHGs) in Kasargod, a coastal district in north Kerala. These groups were designed as a strategy for poverty alleviation, and also to increase women's access to resources and power in household decision-making. The success of the adoption of mussel farming by the SHGs in Kasargod and its impact in other realms within the same villages and in other distant regions are very clear.

- Youth women in farmer groups: the survey indicated that the majority (35 percent) of the women farmers in Kasargod who belonged to SHGs were young, in the age group 21 to 30 followed by 32 percent in the 31 to 40 age group.
- In contrast, the majority of the women farmers who owned family farm units were in the 31 to 40 and 41 to 50 age groups with only 12 percent in the 21 to 30 age groups.

The major impact of the technology was that the women in rural areas began to get an opportunity for self-employment. The survey indicated that for 63 percent of the women who adopted mussel farming, this was their sole source of income. About 21 percent of the women had coir making as a supplementary source of income and 11 percent were involved in agriculture and 5 percent worked as labourers in other areas.

A recent survey among oyster farmers as a part of the NAIP programme and earlier in 2005-2006 indicated that all the women farmers utilized the profit to repay loans, debts, for children's education, health care, house purchase and children's marriages. Thus, the whole family has benefited. There is mobilization of funds and to a large extent the financial liability of the rural households is greatly reduced. The concept of microfinance has also supported this development.

3.5 Leadership development in women

The fact that women increased the farm area and intensity of farming shows that they became efficient aqua-planners and aqua-managers and it also proved that women are better carriers of development. Their prompt repayment of loans increased the faith of the bankers and the schemes of helping groups continued over the years. In the present study it was found that women are all-round players, right from planning to utilization of profit. One very significant outcome is the opportunity that emerged in the villagers for women to prove their inherent capacity to take up responsibility and lead others who are less able.

3.6 Development of ancillary industries through mussel farming in Kerala

The widespread adoption of mussel farming led to part-time jobs through the development of several ancillary industries servicing the mussel farms in Kasargod, Kozhikode, and Malappuram. Several small business enterprises that supply other inputs for farming have also been established.

3.7 Development of new markets and value chains

Commercialization of bivalve farming has led to the development of several new value chains in the state. Initially the markets were within 5 km radius of the farm site in the village. Now the farm produce is sold as live oysters/mussels and also as value added products. The latter has led to the expansion of markets to areas several hundreds of kilometers away from the farm site. Live oysters have been taken even to the Hotel Taj, Mumbai from farmers near Kochi.

4. Lessons learned

The successful diffusion of bivalve mariculture, particularly mussel farming, is the result of a combination of factors, chiefly the availability of suitable waterbodies, a high rate of education, the proximity of mussel markets and a high degree of mussel consumption in the area, and a unique synergy between technology developers, promoters, and credit advancers. This development scenario can work as a role model for other states and developing nations where similar hydrological, social, and market environment exists.

The CMFRI has recently taken up an ambitious R&D programme funded by the World Bank to speed up technology adoption in oyster farming in the states of Kerala, Goa and Maharashtra. Through a value-chain approach, it is planned to develop depuration units, value-added products units and an oyster hatchery along the west coast ensuring supply of spat through remote setting. Of interest is the recent attention in live oyster consumption in high-end restaurants in metropolitan cities linked to the backwater tourism industry. Initial results indicate that the unit price of oysters can rise by more than ten times through this value-chain and can function as a means of attracting new farmers and increasing production.

In oyster and mussel farming, knowledge of the time of spatfall is very important for farmers to decide on the time for setting spat collectors. This is particularly important when the current farming practice is wholly dependent on natural spat as seed. Through a project funded by the Department of Biotechnology (DBT), the CMFRI has achieved preliminary success in developing

PCR based protocol for identification of mussel and oyster larvae from a cocktail mix of various holo and meroplankters (as found in a plankton collection).

A recent advancement is the development of a neutraceutical from Indian green mussels, again by scientists of CMFRI, called GME (green mussel extract) that has been found to have definitive anti-arthritic properties mimicking the pain killer drug aspirin. This drug, which is now undergoing field trials, is surely a means of value addition to mussels, and bound to improve incomes of mussel farmers.

5. The way forward

It is quite clear from the fast pace of its development in the state of Kerala that bivalve farming can develop as a new sunrise mariculture industry in India. Unlike other aquaculture industries, it is not capital intensive and offers great scope for improving the incomes or the rural fishers as an alternative livelihood. But primarily, what has spurred its growth in Kerala is the considerable demand for the produce among the populace. Other bivalve consuming states such as Karnataka, Goa and Maharashtra are being targeted in the next phase of development. To ensure the sustained development of this new industry policy-makers and planners need to:

- promote bivalve farming in all maritime states of India using Kerala as a model of development;
- develop methods to collect seeds from the wild since farming depends on seed availability from natural sources or, alternatively, develop mussel hatcheries for meeting the increasing demand for seed;
- determine the carrying capacity of backwaters/estuaries for bivalve farming and restrict farming accordingly;
- conduct awareness campaigns for improving bivalve consumption in India;
- encourage value added products (VAP) for bivalves to increase marketing possibilities (especially live oysters) and to make the farming practice more remunerative; and
- formulate schemes to promote certification of farmed bivalves by the Marine Stewardship Council (under enhanced fisheries criteria) and the Aquaculture Stewardship Council in order to tap better markets.

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Country Paper 8: Integrated approach to trout farming for productivity enhancement

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Abstract

The technology of trout farming was developed and disseminated to farmers in Nepal beginning in 1998. The successful dissemination of rainbow trout culture technology led to its expansion in the Himalayan region. Out of a potential 54 districts, 21 districts are now practicing rainbow trout farming. There are about 90 farmers, producing nearly 236 mt trout from an area of 140 000 m^2 with an average productivity of 168 MT/ha. They produce an adequate amount of seed and feed themselves. The feed is produced using locally available ingredients mostly.

Trout culture needs continuous flow of clean and cold water. Generally, concrete raceways are constructed for use as culture units. The growing season mostly starts during February when fingerlings are stocked at 75 to 100 fingerlings per m^2. Most of the trout growers in Nepal use their own farm-made feed with approximately 35 percent protein contents. Feeding is normally done two to four times a day at 3 percent to 5 percent body weight. Regular cleaning of raceways, water management, salt water treatment, growth check-up, frequent removal of silt from reservoir tanks are common practices performed by the growers for the health of the fish and water quality management. The fish normally attain marketable size (200 g) within 10 to 12 months with the productivity of 16 kg/m^2. The average cost of production is about USD5/kg. The fish fetch profitable market price of USD8/kg or USD9/kg. The net benefit of trout farming is about USD4/m^2. Therefore, the farmers even with small landholdings can make a good living from the business. In addition, most of the trout farms are integrated with restaurants to add value and generate more income. Trout farming is completely feed-based and there is lot of effluent coming out of the system, but these waters are used for vegetable farming and the effluent load is reduced considerably to avoid any adverse effect on the environment. Instead, it provides fresh and organically produced vegetables for the restaurants in the trout farm giving additional income.

Trout farming has efficiently utilized the otherwise unused resources such as "sloppy" lands and flowing waters to produce highly nutritious food, and has improved the incomes and livelihoods of the rural farmers, and provided employment to the women and youth. Trout farming activities such as feeding, cleaning, cooking are gender friendly activities. It has promoted domestic tourism and its integration with the restaurant business has promoted a local value chain development for the sector.

Introduction

Nepal is predominantly a mountainous country and 77 percent of its area is covered by hills and mountains. Nearly 50 percent of the population resides in these areas whereas only 10 percent of the land is suitable for agricultural activities. In addition, it has tremendous variation in elevation across its 200 km width. Nepal has an area of 147 181 km^2, which can be divided into three physiographic regions, from south to north: the Terai plain, the mid Hills, and the Himalayas. Mountains and hills make 77 percent of the area of Nepal, with the Terai occupying only 23 percent (Table 1). The Himalayas in the north strongly influence the climate of Nepal. The country may be divided into three climatic zones according to altitude: sub-tropical in the Terai, temperate in the Hills, and alpine in the Himalayas. These geographical zones are endowed with many water resources and approximately 5 percent of the total area is in the form of rivers and streams, lakes, reservoirs, ponds and swamps. Among these, the rivers represent about 49 percent of the total water area. It is one of the major countries in Asia having abundant cold freshwater resources; however, these water resources have been poorly used. There is a high potential to cultivate cold water fish in the country, particularly in the hilly region where cold water streams prevail. People living in the hilly region have fewer opportunities to increase their incomes and improve their livelihoods. Cold water aquaculture could be an important source of incomes and provide jobs to the people living in such regions. It can also support ecotourism through developing recreational based fisheries for tourists in hill streams.

Table1 Geographical information on Nepal

Geographical region	Altitude (m)	Area coverage (%)	Land suitable for agriculture (%)	Population (%)
Mountain	4 878 to 8 846	35	2	7.3
Hill	610 to 4 877	42	10	44.3
Terai	<610	23	80	48.4

1. Development of trout culture

Nepal is rich in cold water streams and rivers. To utilize these natural resources for the benefit of its people through the development of cold water aquaculture, trout was introduced into Nepal from the United Kingdom (UK), Japan, and India in the late 1960s and 1970s. The first attempt was made in 1969 by importing Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) from Kashmir, India, rainbow trout (*Oncorhynchus mykiss*) from the UK, and sockeye salmon (*O. nerka*) from Japan during 1979-1980, but it failed because of inadequate technical know-how and the lack of skilled manpower. Later in 1988, rainbow trout (*Oncorhynchus mykiss*) was re-introduced from Japan. Approximately 50 000 eyed eggs were imported. The eggs were successfully hatched and reared in research stations.

1.1 Technology development

Since the successful introduction of trout in the country, experiments were initiated focusing on feed ingredients, water quality, breeding, fry nursing and rearing, nutrition and feed management, raceway design and construction, along with health management practices and packages of practices were developed. A technical package was developed by 1998 and farmer level field trials were conducted. After the successful demonstration of the trout production package, efforts were concentrated on a participatory programme for scaling up operations. The government was convinced and trout was included in the "one village one product" campaign in 2007. Since then, trout has received priority in the country's aquaculture development.

1.2 Status

This short history of 17 years of commercial trout culture in Nepal has established 95 trout farms with 862 raceways covering of 23 650 m^2 and producing 234.2 mt annually from 22 districts. The production of trout has grown rapidly since 1998 (Figure 1). The seed requirement is about 2.35 million fry (0.5 g to 1.5 g). Most of the seed (90 percent) requirement is fulfilled by 18 private hatcheries. There are 15 local feed manufacturers and recently a commercial feed factory was set up. The average growth rate obtained is 64.4 percent compared to overall aquaculture growth of 8.4 percent. Similarly, trout productivity is nearly 125 mt/ha compared to carp culture productivity of 4.35 mt/ha. In addition, the average annual income from a trout farm (250 m^2) is USD2 500. Trout farming in a 200 m^2 raceway is good enough to support a family and provide economic security. Moreover, on average each trout farm provides direct employment to at least five people.

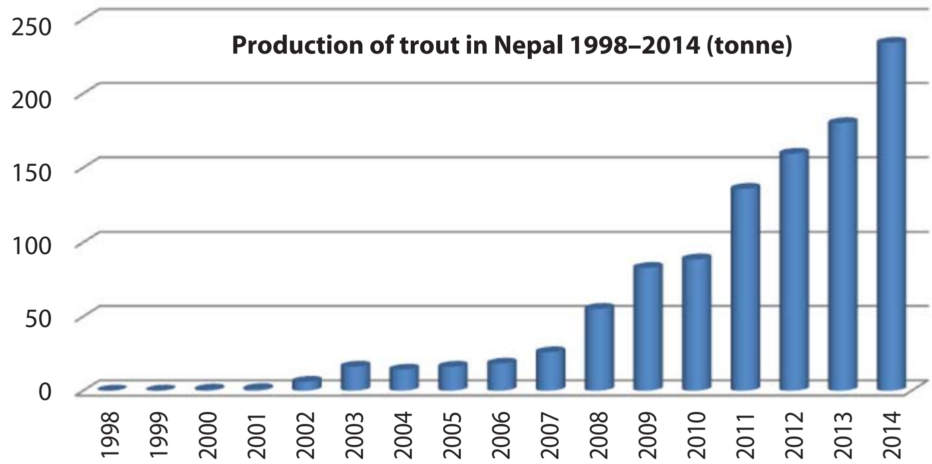

Figure 1 Production of trout in Nepal 1998–2014

1.3 Culture technique and prerequisites

Trout is produced mainly in a flow through system with high stocking density and complete feeding. Trout needs clean and cold water for its growth. Concrete raceways of various shapes and sizes can be used. However, rectangular raceways are normally used for trout culture. Earthen ponds are not very common but some successful examples also exist in Nepal. The suitable size and depth of the ponds are 50 m^2 to 150 m^2 and 80 cm to 90 cm, respectively. Most of the farmers in Nepal purchase trout seed from trout seed producers and stock them in their raceways, which can be linear or parallel depending on the availability of water resources. The fish are grown until they attain market size, which is about 200 g to 250 g. Fish are fed with locally prepared or commercially available pellet feed. These feeds are available in different recommended sizes based on the size of the fish. The important aspects to be considered before deciding to take up trout farming are given below.

1.4 Site selection

The selection of a suitable site is essential for a successful trout farm and business. The best site for establishing a trout farm should have preferably a slope of 1 percent to 3 percent to permit adequate water flow and maintain water quality. A favourable climatic condition, easy access to roads, availability of electricity, security, free of poaching, market availability and safe from flooding are also important factors that need to be considered during site selection.

1.5 Rearing facilities

If the water supply is reliable, permanent, stable and adequate, ponds can be constructed in parallel fashion to avoid contamination. But, if the water source is limited then linear raceways for holding trout should be constructed. However, a filter chamber is installed to clean the used and polluted water before sending it to other raceways.

1.6 Water quality

An adequate volume of cold water below 20ºC throughout the year is the prerequisite for trout culture (Table 2). Rainbow trout grows well at a temperature between 10ºC and 20ºC, but in Nepal research shows the best growth takes place in a temperature between 16ºC and 18ºC. Feed consumption decreases when water temperature increases above 20ºC, resulting in feed loss, slow growth and eventually death if exposed to a higher water temperature for long period. Trout requires more than 7 ppm dissolved oxygen (DO) in its water for proper growth and breeding. The optimum pH range for trout is between 6.5 and 8.0 with optimum value between 7.0 and 7.5.

Table 2 Water exchange requirement at various stages of trout farming

Purpose	Size			Area (m^2)	Flow rate (litre/second)
	Length (m)	Breadth (m)	Depth (m)		
Incubation (Atkin)	2.5 to 3	0.4 to 0.5	0.5	1.5	1.5 to 2
Hatching tub	2.5 to 3	0.5 to 0.6	0.5 to 0.6	5	1.5 to 2
Nursing/rearing tank	15 to 40	0.75 to 1.25	0.7 to 0.8	10 to 50	2 to 2.5
Table fish production	30 to 50	1.25 to 3	1	50 to 150	5 to 6

1.7 Grow out culture of rainbow trout

Trout is stocked at 50 fish/m^2 to 100 fish/m^2 depending upon the water source, the quantity, the quality and its flow rate. At this stocking rate the marketable size of 200 g to 300 g is reached after 10 months to 12 months of culture period. However, fish need to be graded in a timely manner to attain uniform growth and avoid cannibalism. Specific growth rate (SGR) decreases with the increasing size of fish. In general, when fed with good quality feed (Table 3) and proper feeding method (Table 4) a feed conversion ratio (FCR) ratio of 1:2 is obtained.

Table 3 Composition of locally manufactured pellet feed

Ingredients	For fingerling	For table fish
	40% protein	35% protein
Shrimp meal	30	20
Roasted soybean	35	35
Wheat flour	17	22
Rice bran	10	12
Mustard oil cake	6	9
Vitamin mix	1	1
Mineral pre-mix	1	1

Table 4 Feeding rate and frequency

Size of the Fish (g)	Rate (% of body weight)	Frequency (No. of times)	Tentative period (days)
0.18 to 1.5 (Fingerling)	5.6 to 7	8	30 days
1.5 to 5.1 (Fingerling)	4 to 5.2	6	45 days
5.1 to 12 (Table fish)	3.3 to 4.1	5	60 days
12 to 62 (Table fish)	3	4	90 days
62 to 250 (Table fish)	2	3	150 days

Size difference in rearing area should be avoided to obtain better survival. This is achieved by regular grading to avoid competition and cannibalism. The size category for separation might be of 2 g to 5 g; 10 g to 20 g; 50 g to 60 g; and >100 g sizes. Such management could also help to improve FCR and minimize production cost. The trout diet formulation depends on the age and size of the fish (Table 5). Rainbow trout needs a high protein diet. The success of research on feed formulation and trials at farmers' fields has helped to establish production of trout feed by the private farms in the country. Generally, the marketable body weight of trout is about 200 g. The longer culture period after 200 g body weight increases production cost. Therefore, it is advised to harvest the fish after it attains this marketable size to get the best profit margin.

Table 5 Recommended nutritional requirement

Nutrient (%)	Stage of fish	
	Fingerling	Table fish
Crude protein	40 to 45	35 to 40
Crude lipids	12	10
Crude carbohydrate	20	25
Crude fibre	1.5	2.5
Essential fatty acid	1.0	1.0

Table 6 Cost-benefit analysis of rainbow trout farming of 200 m²

I. Capital cost				
Description	**Cost (NPRs)**	**Economic life (year)**	**Depreciation (NPRs)**	
Raceway construction	652 000	20	32 600	
Water supply	224 000	20	11 200	
Store/feed house	181 000	20	9 050	
Nets, cages, hapas, graders	18 000	5	3 600	
Pumps and balances	12 000	5	2 400	
Buckets/crates etc.	7 000	2	3 500	
Total	1 094 000		62 350	
II. Operating cost				
Description	**Unit**	**Quantity**	**Rate**	**Total NPRs**
(a) Variable costs				
Seed (2 g size)	No	15 000	8	120 000
Feed for initial rearing	kg	375	150	56 250
Feed for advance rearing	kg	6 000	110	660 000
Tools and chemicals	LS			12 000
Electricity	month	12	1 000	12 000
Communication	month	12	1 000	12 000
Transportation	LS			30 000
Others	LS			12 000
Total (a)				914 250
(b) Fixed costs				
Salaries (manager)	M/M	12	12 000	144 000
Salaries (staff)	M/M	24	6 000	144 000
Land rent (500 m²)	LS			10 000
Interest on capital@14%				153 160
Depreciation				62 350
Maintenance@5% of capital cost				54 700

Table 6 Cost-benefit analysis of rainbow trout farming of 200 m² *(continued)*

Description	Unit	Quantity	Rate	Total NPRs
Miscellaneous	LS			12 000
Total (b)				580 210
Total annual cost (a + b)				1 494 460
Income and profit				
Gross income	kg	2 500	750	1 875 000
Cost of production/kg				598
Net profit				380 540
Profit/kg				152
Rate of return (%)				25

In trout farming in Nepal, low feed efficiency is experienced (43 percent to 46 percent) and there is a need for research on trout feed efficiency improvement. The cost of rainbow trout production has been analyzed and showed that to produce 1 kg of marketable size (200 g to 300 g each) of trout might cost nearly Rs.598. Economic analysis of trout culture based on the experiences of the private sector in Nepal showed that the annual rate of return could be nearly 25 percent of the total investment (Table 6). The high initial investment for raceways construction is a major constraint for rapid expansion of trout cultivation that needs to be addressed by researchers in the future.

1.8 Practice adoption

Trout farming has become a success in Nepal after more than a decade of continuous efforts by many governmental and non-governmental organizations including the donors. Among these, the most prominent are the Fisheries Research Division, Fisheries Research Centres Godavari and Trishuli, the Directorate of Fisheries Development, the National Fisheries and Aquaculture Development Program, the Central Fish Laboratory, the District Agriculture Development Office, the Project for Agricultural Commercialization and Trade, the High Mountain Livelihood Improvement Project, the Federation of Nepal Chamber of Commerce and Industry, Japan International Cooperation Agency and the farmers.

2. Main drivers of successful adoption

2.1 Resource availability

The main drivers of successful adoption of trout farming are the vast potential available resources, low land and labour productivity of the agriculture sector, and the limited livelihood opportunities in the hilly region. The contributing factors for the successful adoption of intensive trout farming are availability of suitable sites and adequate quality and quantity of water. Similarly, simple technology and efficient technology transfer mechanisms along with technical backstopping and the availability of major inputs such as seed and feed along with the changing perceptions of people and the socio-economic environment encouraged farmers to take up trout farming. Also playing a part were the high market demand for the product, the government's priority to solve the nutritional problem and the comparative advantage of the commodity, which has high productivity and profitability. In addition, recent favourable government policies (related to insurance, soft loan, subsidies) and programmes (matching grant, participatory development) along with the media and consumer support in addition to economic sustainability and increased high productivity have helped the industry to achieve a very high growth rate.

2.2 Promotion

The Nepal Agriculture Research Centre through its Fisheries Research Division and centres has been supporting rainbow trout farmers since 1998 on site selection, culture and breeding in the form of a participatory research programme on their land. Similarly, the Japanese International Cooperation Agency (JICA) supported follow-up projects established on three private farms with hatcheries and nurseries (two in Nuwakot and one in Rasuwa districts) and were supported to scale up rainbow trout farming for the enhancement of livelihoods of the hill community in Central Nepal. Three private trout breeders were developed, and about 200 000 fry were produced and distributed by the end of the project. Various stakeholders associated with trout farming were trained for better technological, managerial and marketing knowledge. In 2006, the Government of Nepal declared Rasuwa and Nuwakot as trout growing districts under the "one village one product" (OVOP) programme (2006/07), which prioritized the promotion of trout farming and local tourism. The OVOP programme was initiated with the aim of scaling up trout farming technology with a private-public partnership (PPP) model. Seed supply was a major constraint for expansion of trout farming as trout fingerlings were supplied to farmers exclusively from the two research stations. Later on, some private farms were strengthened and since 2006 participatory breeding technology has been transferred to the private sector. Similarly, feed was another constraint. A feed mill to produce pellet feed was set up initially to promote trout farming by providing machines to the private sector followed by the development of a local pellet machine. At present there are 15 feed manufacturing farmers meeting the demand. A health management and sanitation plan was developed and transferred to farmers along with the grading techniques, which has led to the successful adoption of technology by the private sector.

3. Impact

The impact created by successful intensification of trout based on locally improvised technology is well recognized in the country. It has not only generated incomes for the farmers but also created employment opportunities for the people living in the mountainous and hilly regions and improved their living conditions. The average annual income from a trout farm (250 m^2) is USD2 500. Trout farming in a 200 m^2 raceway is good enough to ensure the food security of a family. In addition, on average, each trout farm provides employment for at least five people. It has also helped in value chain development. Moreover, it has increased the demand for local agri-products and has supported the growth of the service and business sector and has promoted internal tourism significantly. It has also provided nutritious food to the people. The impact is so strong that one of the national highways is commonly known as "trout highway". It has engaged all the family members in creative work and kept them in good health.

4. Lessons learned

4.1 Successful practices

Farmers exclusively engaged in table fish production make less profit than farmers who integrated into other sectors, particularly hotel/restaurant businesses. The risk bearing and investment capacity of farmers has improved. Similarly, their confidence level has increased. It has stimulated and encouraged others to enter the business and thus the economic health of the whole area improved. Not only that, the productivity of agricultural crops, which receive water from the raceways, has increased and the agricultural products also fetch better prices as these are sold as organic products. The same water can be used in a number of raceways, for mill operation, for hydropower generation and irrigation and thus increase efficiency and sustainability. Locating the settling chamber at the tail end of the farm reduces the nutrient load and releasing the farm discharge into the crop cultivation area also reduces nutrient load substantially. Other businesses and services also get a boost when the farms are integrated with other businesses. Here, the participatory and group approach facilitates technology transfer.

4.2 Gaps to fill

- The feed used is locally produced sinking pellet feed. The FCR is above 2 and FCE is also poor.
- The average productivity obtained is only 12.5 kg/m^2, whereas under similar conditions in many countries it is about 20 kg/m^2.
- Inadequate research and extension support because of limited number of skilled professionals. Only a few trout culture districts have fisheries technicians working in their district.
- Health and environmental management issues are insufficiently addressed.
- Old genetic stock and lack of any selective breeding programme for genetic improvement.
- Marketing and post-harvest issues are not addressed properly by research.
- Poor feed quality (nutritional balance, cost, raw materials).
- Seed transportation problem (topography, limited access and poor road conditions).
- Lack of specialized manpower in nutrition and health.
- Inventory and zoning practices for aquaculture have not yet been developed.
- Poor post-harvest and marketing facilities (cold chain, transport, processing).

5. The way forward

The economic efficiency and other indicators show that the potential for further development of trout culture exists in the country and also in the region. However, some innovative efforts are needed to accelerate its growth.

5.1 Technical improvements

The available technology on trout farming has shown quite satisfactory results. However, there are many areas that still need improvement. Research should focus on improving production efficiency as this will further encourage farmers to enter the trout farming business.

5.2 Improvement in technical support

Fish farming is not a traditional farming practice of the hill people and often they have limited knowledge about fish culture. Trout farming is scattered and mostly in remote areas. Strong technical support services are, therefore, required for further expansion of trout culture and for upgrading present practices. The technical staff to provide technical backstopping at the grassroots level should be available to help interested farmers to enter the business and provide technical support services as and when required. As such, the extension mechanisms are still rather inefficient in upgrading and scaling up trout production. Therefore, reallocation of technical manpower at all level needs to be increased significantly.

5.3 Development of market information and facilities

The market plays a significant role in the growth of any sector. The economic return to farmers is highly dependent on market exchanges. Farmers on rural areas have poor access to reliable and timely market information, which often results in difficulties in marketing their products at reasonable market prices and profit margins. At present, the demand for trout is quite high as the volume of production is small. With increases in production there could be problems related to profits and sale of the product locally in remote areas. Therefore, development of an adequate and an efficient market and marketing network will be needed. Facilitation and promotion of farmers groups, cooperatives and associations in input as well as output marketing may be an effective approach to assist individual farmers in addressing marketing problems. Similarly, branding the product as Himalayan trout and maintaining international standards might help farmers to find good international markets. In addition, government facilitation and sharing of successful experiences across the regions and sectors are also very important.

5.4 Continuity in government policy

Aquaculture as a whole is a priority sector and many supporting policies such as incentives, subsidies, loan support, matching grants and various capacity building programmes exist for all aquaculture activities. In addition, trout farming has some very successful programmes such as participatory development and public-private partnerships. Above all, the government also provides a 75 percent subsidy on insurance premiums. All these policies need to be continued.

5.5 Improving investment capacity

Small rural households in remote and hilly areas are usually among the disadvantaged groups in terms of economic and social conditions. Hence, they are not able to develop efficient aquaculture operations without public support. Trout farming needs high capital as well as operational investment, and it is often difficult for many farmers to manage the required investment for rearing facilities and inputs essential for production. Therefore, an appropriate institutional mechanism needs to be in place to enable farmers to have easy access to soft loans for investment.

5.6 Improved supply of quality inputs

Economic viability, efficiency per unit production and sufficiency of income are very important for trout culture if it is to make a significant contribution to food and nutritional security, and improve rural livelihoods. A good supply of certain key material inputs for effective production is of great importance and the supply of quality fish seed and feed is the most crucial among them, otherwise aquaculture development will be seriously constrained. Therefore, efforts should be made to establish national capability to ensure the supply of high quality fish seed in the long term. Use of high quality floating pellet feed is an essential way to improve the production efficiency. There is a need to develop cost-effective feed using locally available ingredients to decrease the cost of production.

5.7 Need for a regional level forum to share expertise

Many countries in the region are already engaged in trout farming and some of them have achieved success and many more have the potentials to develop trout farming in highland and remote areas. They have similar national development needs, socio-economic and natural conditions. At the same time, they also face similar constraints. Collaboration among them can significantly facilitate the development of trout farming and make a great contribution to the improvement of livelihoods and social development in such areas. However, carp culture still dominates the region and not many regional efforts to develop cold water aquaculture in general and trout culture in particular. Therefore, it is strongly suggested that a regional forum should be established to discuss common problems faced and share successful experiences and take up a joint research programme to overcome the technical hurdles without duplication of resources. Similarly, other countries in the region have potential but are lagging behind because of poor technical knowledge; they should also get support from the experienced countries and should get the benefit of their experience. Regional collaborative activities are also greatly needed in the area of human resource development through international training and exchange visits. Selection and maintenance of good strains as well as genetic improvement of trout in the region is equally important for the growth of trout farming in the region. The simple technique of trout production, which is easily practiced by farmers of Nepal, may be useful to countries with a similar socio-economic background.

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Country Paper 9: A science-based management approach for sustainable mariculture in Hong Kong SAR

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Abstract

In Hong Kong SAR, marine finfish culture is mainly carried out in cages suspended by floating rafts in designated coastal waters, named fish culture zones (FCZs). These zones are mostly located in semi-enclosed and weakly flushed coastal tidal inlets that provide shelter against typhoons and waves. This paper describes the successful application of WATERMAN – a science-based fisheries management system – for sustainable development of mariculture in Hong Kong SAR. The WATERMAN system is based on a unique integration of mathematical modelling and field studies, and provides quantitative determination of the carrying capacity of existing and potential FCZs in Hong Kong SAR. The system accounts for factors that include tidal flushing, pollution loading from fishfarms, phytoplankton dynamics and nutrient recycle, sediment-water interactions, and statutory water quality objectives; it also caters for different seasonal and environmental scenarios. Using WATERMAN, we determined the carrying capacity of all the existing FCZs in Hong Kong SAR. Based on the findings and taking into consideration other factors, the Agriculture, Fisheries and Conservation Department (AFCD) recently launched a pilot scheme to issue new marine fish culture licences for fishermen to practice mariculture in three FCZs having surplus carrying capacity. The WATERMAN system also identified some overloaded FCZs, suggesting a need to reduce the stocking volume and/or increase the culture area. The AFCD, therefore, plans to expand one overcrowded FCZ by rearranging and spreading out the existing rafts within the expanded zone to improve the culture environment. The WATERMAN system is also used to help identify potential new sites for fish farming, thereby strengthening the sustainable development of mariculture in Hong Kong SAR.

Introduction

Before 1982, marine fish culture in Hong Kong SAR was conducted on an *ad hoc*, unregulated manner. The Marine Fish Culture Ordinance (Cap. 353) came into effect in 1982 and required all marine fish culture activities to operate under licence in designated fish culture zones (FCZs). At that time, there were 24 designated FCZs. As the industry continued to grow, there were 1 810 licensees operating in 28 FCZs in December 1988, with another 1 298 applications for fish culture licences on the waiting list, pending the identification of suitable new FCZs/raft areas. Meanwhile, there was a rising concern in the community that not only would mariculture suffer from poor water quality if the size of the industry continued to grow, it would also generate pollutants and thereby degrade the marine environment. In 1989, the government commissioned a consultancy to assess the environmental impact of mariculture in Hong Kong SAR. As an interim measure, no new FCZs were to be designated, except for forced re-siting necessitated by public works. In 1990, the government endorsed various recommendations from the consultancy (Ove Arup and Partners, 1990), including the continuation of the moratorium on the designation of new FCZs, and stringent restrictions on the granting of new licences or raft area extensions in existing zones. Since then, only one new FCZ has been designated to accommodate mariculturists from an FCZ that has been degazetted to make way for a public works project. The extension of zone areas has been permitted in six FCZs solely for the purpose of allowing reduction of raft density, and no new fish culture licences have been issued.

In the past 20 years, there have been changes in the operational mode and business environment of local fish culture activities, which helped to reduce the pollutants released into FCZs and improve the marine environment in their vicinity. These developments included: (i) the reduction in raft area as a result of drop-outs, cancellation of licences, and management measures that encouraged the relocation of fish culture rafts from overcrowded FCZs to thinly populated zones; (ii) the improvement in feeding regime because of the use of pellet feed replacing "trash" fish; (iii) better management of refuse/fish carcass collection and disposal; (iv) enhanced law enforcement against domestic dwellings on rafts; (v) reduction in stocking density as a good aquaculture practice; and (vi) deployment of specially designed artificial reefs as biofilters at some FCZs. All of these developments resulted in a significant reduction in nitrogen and pollution loading from mariculture activities into the local waters and thereby improved the marine environment. In the light of current circumstances and the need to facilitate the sustainable development of mariculture in Hong Kong SAR, a review of the moratorium was sought in 2010.

1. WATERMAN coastal water quality management system

The AFCD completed the review in 2012 based on an objective and scientific assessment of the environmental acceptability of current mariculture activities in existing FCZs, which drove policy-making to improve the overall production efficiency and social acceptance of the mariculture industry. The assessment was performed with a fisheries management system recently developed by the research team led by Professor Joseph Lee of the Hong Kong University of Science and Technology. The system, named WATERMAN,[1] is a computer database/modelling system, governed by factors such as tidal flushing rate of the site, organic loading from fish farms, and the statutory/indicative water quality objectives applicable to the local waters. It adopts a very conservative approach, taking into account several parameters related to environmental fluctuations, extreme weather, hydrological and environmental scenarios, including slack tides, seasonal stratification and algal blooms and through the unique integration of mathematical modelling and field studies it determines the maximum allowable fish stock of a fish farm site for sustainable and environmentally acceptable fish farming.

Sustainable management of mariculture requires the proper siting of a fish farm with appropriate stocking density control. The carrying capacity of an FCZ refers to the maximum fish stock that can be supported by a fish farm site in a sustainable manner. Beyond this capacity, water quality problems such hypoxia, algal blooms and red tides are more likely to occur. The WATERMAN fisheries management system is based on a general framework (Figure 1) to assess the carrying capacity of a fish farm (Lee and Wong, 1997; Lee and Arega, 1999, Lee *et al.,* 2003; Choi and Lee, 2004).

Using the analogy of an aquarium or a fish tank, the carrying capacity of a fish farm is the amount of fish that can be sustained in good health in the finite size "tank". The main difference is that in an aquarium, the renewal of "clean water" is provided mechanically using a pump device, whereas water renewal in an FCZ relies on nature's power of tidal flow exchange with the open sea, a process known as tidal flushing. The self-purification capability of a coastal water body is a result of the tidal exchange with the outer sea and turbulent dispersion.

[1] Project WATERMAN was developed from a HK$29.8 million grant awarded by the Hong Kong Jockey Club Charities Trust to the University of Hong Kong in 2009.

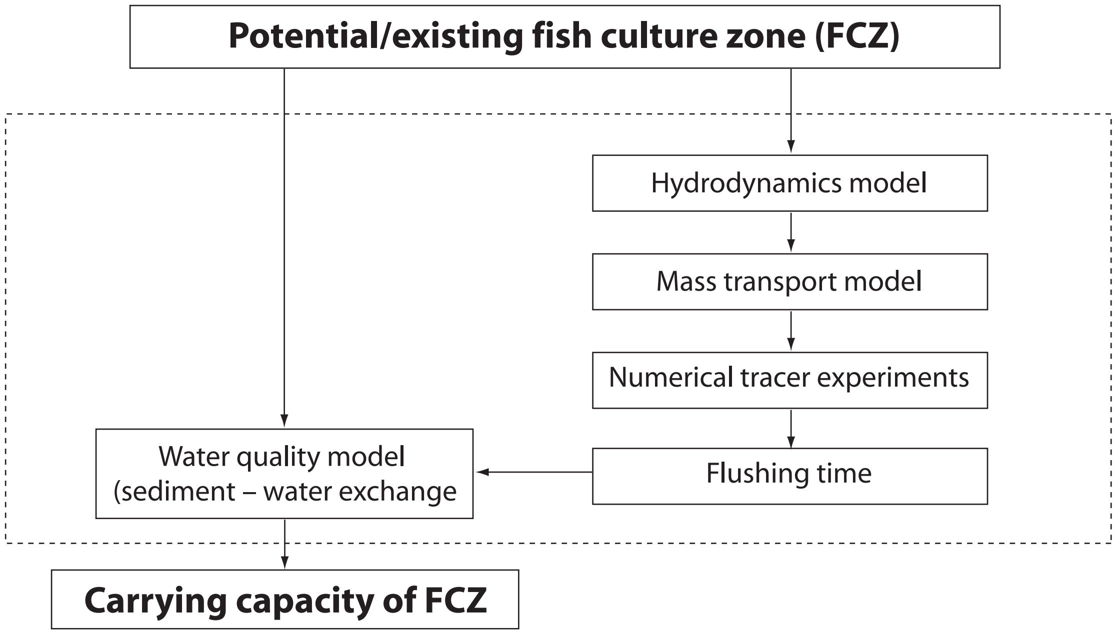

Figure 1 Schematic framework of modelling of carrying capacity of a fish farm

An FCZ is treated as a system that receives pollution loading from its fish farming activities, and becomes "clean ocean water" by tidal exchanges with the open sea (Figure 2). The flushing rate is the most important physical parameter for the environmental management of mariculture. This represents a lumped measure of the effectiveness of tidal flushing in removing any pollutant in a fish farm. In Hong Kong SAR, tidal currents are driven by coastal tides, offshore ocean currents, and also influenced by the Pearl River as well as inland freshwater discharges. Typically, Hong Kong's SAR coastal water is vertically density-stratified in the wet season (Lee *et al.,* 2006).

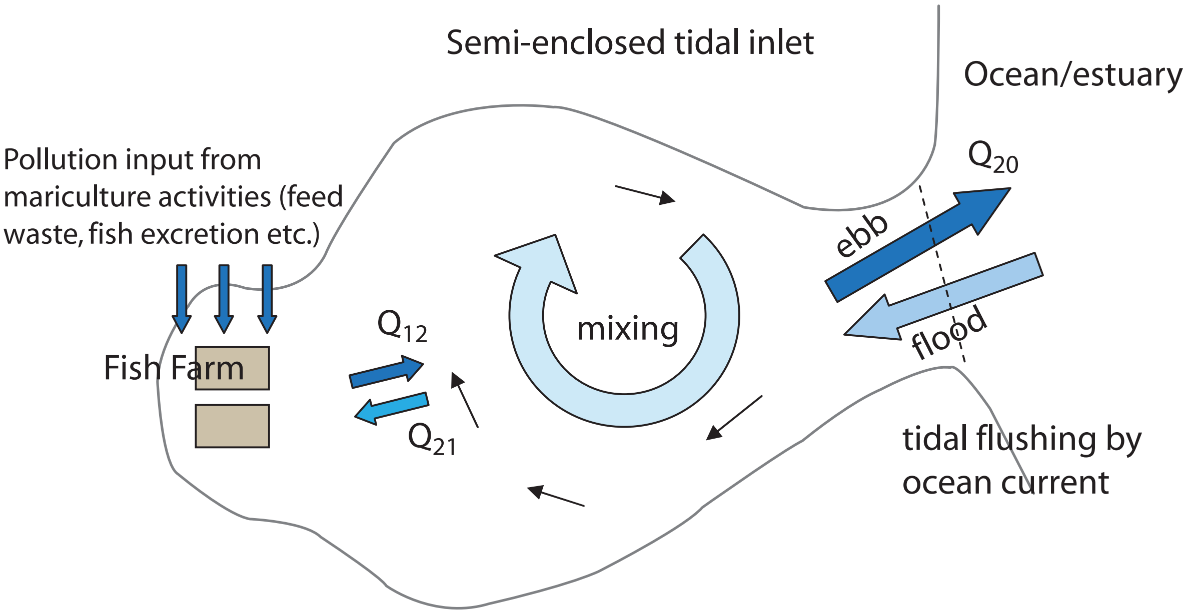

Figure 2 Pollution input and tidal flushing in a fish culture zone in a semi-enclosed bay

A numerical tracer method has been developed to determine the flushing time (the inverse of the flushing rate) of an FCZ (the system). A prescribed mass of conservative tracer is released in the system, and the subsequent transport of the tracer by tidal currents and turbulent dispersion is computed using a three-dimensional (3D) hydrodynamic model. Based on the decrease in tracer mass in the FCZ with time, the flushing time (or flushing rate) of the fish farm can be determined (Choi and Lee, 2004). A higher flushing time represents a longer time required for pollution removal and hence a poorer self-cleansing ability. As the fish farms are usually situated in well-sheltered shallow embayments that may not connect directly to the open water, it is found that it is necessary to define both "local" and "system-wide" flushing times to represent the effectiveness of the mass exchange with the surrounding waterbody and the open sea respectively. The "system-wide" flushing time is determined by looking at mass removal from a much larger waterbody that is connected to an adjoining "clean" ocean. It takes into account the interactions between different parts of the waterbody that are not assumed to be "clean" and represents the long-term flushing efficiency of the region of interest. Hence, it could be used for determining the long-term water quality.

The flushing time is a measure of the self-cleansing capacity, but the water quality in the FCZ (hence, carrying capacity) depends on other factors as well, for instance the water depth, size of FCZ, and organic loading. A box water quality model can simulate the sediment-water-pollutant interactions to predict long-term (seasonal) average water quality in an FCZ. Besides the water column, two well-mixed layers (thin aerobic layer and thick anaerobic layer) are included in the model to represent the active benthic sediment layer. The model simulates key hydro-biological processes in the water column including: phytoplankton growth/mortality, oxygen consumption/production by the biochemical activities, nutrient and material recycling, and sediment-water exchange. The modelling simulation is based on the principle of mass balance and includes expressions for the diagenesis reaction, the sinks and sources terms in the water column and each of the two sediment layers. The WATERMAN water quality model was calibrated and extensively tested with past field data for individual FCZs. Both steady-state and year-long unsteady simulations were conducted for model validation.

With the flushing time reliably determined individually, water quality model simulations can be carried out for each FCZ under different fish stock loading conditions. The maximum permissible loading, i.e. the carrying capacity, can be determined by increasing the fish stocking (and hence pollution loading) until one of the key water quality objectives (including dissolved oxygen, potential lowest dissolved oxygen, inorganic nutrients and chlorophyll-*a*) is violated under specific scenarios.

In practice, uncertainties and fluctuations in the weather, different hydrodynamic and environmental conditions as well as farming practices would also affect the carrying capacities. To assess the response of the carrying capacity to the different scenarios, a series of steady-state water quality simulations under different hydro-meteorological conditions and pollution loadings are carried out. Hence, the maximum permissible loads and fish stocking level for different scenarios are obtained, from which the capacity corresponding to different safety margins (e.g. 99 percentile, 95 percentile and 90 percentile) can be determined.

1.1 A science-based management approach

The carrying capacities of the 26 FCZs in Hong Kong SAR were determined by WATERMAN in 2011 (Table 1). By comparing the estimated fish stock in an individual FCZ against its carrying capacity, we identified 15 FCZs that had surplus carrying capacity and, in contrast, 11 were found to be overloaded. The former cases may indicate that we are probably underutilizing our FCZs, and these may allow holding of additional fish stock without compromising the marine environment. On the other hand, the latter cases suggest the need for appropriate measures to reduce fish stocking density in order to achieve environmental acceptability and sustainability. Taking into consideration other factors, including the mode of operation, farming status, concurrent development works, and occurrence of extreme environmental fluctuations, the AFCD proposed to issue new fish culture licenses through a one-off allocation scheme in three selected FCZs, namely O Pui Tong, Wong Wan and Sham Wan FCZs, having surplus carrying capacity. The AFCD also proposed to expand one selected FCZ, Yim Tin Tsai FCZ, with current stock beyond its carrying capacity to thin out the mariculture rafts.

Table 1 Estimated carrying capacity and fish stock in 26 FCZs in Hong Kong SAR

Fish culture zone	Zone area (sq. m)	Calculated capacity (kg)	Stock in 2011 (kg)	Additional capacity (kg)
Ap Chau*	4 200	2 100	2 311	-211
Cheung Sha Wan#	214 200	206 100	82 330	123 770
Kai Lung Wan*	27 045	18 600	29 690	-11 090
Kat O*	32 400	20 400	24 726	-4 326
Kau Lau Wan#	11 200	10 100	6 453	3 647
Kau Sai*	46 200	65 400	66 608	-1 208
Leung Shuen Wan*	17 300	19 500	33 368	-13 868
Lo Fu Wat*	5 400	3 600	4 734	-1 134
Lo Tik Wan#	109 200	16 500	118 478	47 022
Ma Nam Wat#	40 100	51 900	25 552	26 348
Ma Wan#	46 300	79 700	74 244	5 456
O Pui Tong#	105 600	101 400	40 657	60 743
Po Toi#	3 000	3 100	1 388	1 712
Po Toi O#	38 200	36 400	22 089	14 311
Sai Lau Kong#	7 200	3 800	1 668	2 132
Sha Tau Kok*	180 000	58 500	88 110	-29 610
Sham Wan#	180 600	168 800	85 702	83 098
Sok Kwu Wan#	141 200	169 800	139 909	29 891
Tai Tau Chau*	62 800	46 700	63 970	-17 270
Tap Mun*	72 400	54 500	58 910	-4 410
Tiu Cham Wan#	17 000	8 800	6 912	1 888
Tung Lung Chau#	80 000	99 400	64 787	34 613
Wong Wan#	22 500	20 500	0	20 500
Yim Tin Tsai*	136 300	92 900	125 492	-32 592
Yim Tin Tsai (E)*	149 500	74 200	105 184	-30 984
Yung Shue Au#	342 000	359 500	216 668	142 832
Total	2 091 845	1 941 200	1 489 939	451 260

FCZ having surplus carrying capacity
* FCZ with carrying capacity overloaded

1.2 Issue of new fish culture licences

With a farm size of not more than 300 m^2 and an assumed stocking density of 20 kg m^{-2}, the AFCD plans to issue not more than 30 new licenses under the one-off allocation scheme to better utilize the surplus carrying capacity at O Pui Tong, Wong Wan and Sham Wan FCZs. We introduce management measures when issuing new fish culture licences and require each applicant to provide a business plan that should demonstrate clearly how the proposed mariculture business could achieve sustainable use of the mariculture environment. A stringent evaluation of the business plan is conducted to assess its potential for promoting the sustainable development of aquaculture, production feasibility, environmental sustainability, and technical and management capability. Additional conditions, for instance, requiring the new licensed area to be actively used for mariculture, prohibiting recreational fishing, requiring the fish farms to join the Accredited Fish Farm Scheme set up by AFCD and/or restricting the use of "trash" fish, may also be imposed to ensure proper implementation of the scheme. In parallel, the AFCD will provide additional technical support and implement environmental measures, such as deploying biofilters in FCZs and installing equipment on-site for continuous water quality monitoring, with a view to creating a favourable operating environment in these FCZs. We foresee that the scheme will be able to demonstrate mariculture development in a sustainable manner, and better utilization of marine resources with no unacceptable impact on the marine environment.

1.3 Expansion of existing FCZs

With a view to thinning out mariculture rafts and improving the culture environment, the AFCD proposed to expand Yim Tin Tsai FCZ, the current stock of which is beyond its carrying capacity. The expansion will involve the designation of a fish culture subzone, which is about 4.5 hectares, one third of the size of the existing FCZ. Mariculture rafts at the existing FCZ will be rearranged and distributed within the subzone. There will be no net increase in the total licensed raft area and no new license will be issued. The AFCD has engaged a consultancy to evaluate the technical and environmental feasibility of the zone expansion. WATERMAN was used to estimate the flushing rate, the pollution loading and subsequently, the carrying capacity of the existing FCZ and the proposed subzone. The water quality before and after the zone expansion was predicted by Delft 3D hydrodynamic and water quality modelling. Based on the estimation by WATERMAN, the carrying capacity of the proposed subzone is about 32 tonnes per year, which is equivalent to the amount of fish production from 23 percent of the mariculture rafts at the existing FCZ. Based on this capacity, about 60 mariculture rafts at the existing FCZ could be relocated to the proposed subzone, resulting in a reduced raft density and an expected improved water quality at the existing FCZ. The consultancy also evaluated other potential impacts associated with the zone expansion, including those on marine ecology, air quality, noise, capture fisheries, landscape and views, cultural heritage, terrestrial ecology, and traffic, and proposed mitigation measures where appropriate. The AFCD will provide technical support and enhanced environmental monitoring to ensure that the proposed expansion will be environmentally acceptable. We will also study the possibility and merits of expanding other overloaded FCZs having regard to the Yim Tin Tsai FCZ experience.

2. Lessons learned

Marine fish culture in Hong Kong SAR is moving from an *ad hoc*, unregulated state to a systematic, science-based, productivity-driven and environment friendly activity. With advances in hydrodynamic and water quality modelling, and a better understanding of our local marine environment, we could formulate our management plan with a sound scientific basis and justification instead of using the traditional trial-and-error approach. The estimation of carrying capacity allows us to assess if the farming activity at a particular site is operated in an environmentally acceptable manner or to decide how intensive or extensive the farming activity can be in order to be sustainable.

However, as the technology is developed and validated mainly for FCZs in the well-protected semi-enclosed bays, its applicability to FCZs located offshore or in more open water areas (locations more influenced by waves and oceanic currents) will need to be further verified. Besides, the modelling exercise requires good data on bathymetry and topography, background environmental status, operational mode, including type of fish cultured and feeding practices, for model set-up and validation. It should be noted that model output is an estimation based on the best available data. Monitoring programmes, including both the water quality and the feeding practices, should be developed in order to ensure environmental acceptability, and to continually refine and validate the model as conditions and practices change over time.

3. The way forward

Environmental acceptability and productivity are the prime concerns when formulating policy and implementing a management strategy for mariculture in Hong Kong SAR. As far as we are aware, our proposed scientific approach is the first hydraulic and water quality modelling system successfully applied for the quantitative determination of carrying capacity to meet both of the above concerns. In moving forward, we will be guided by the principle that any proposed measures to be taken should satisfy the prevailing test of environmental acceptability. Apart from making better and wise use of existing FCZs, the AFCD is exploring the possibility of identifying suitable sites for designation of new FCZs for mariculture operation. We will again be guided by a science-based approach to first short-list potential sites through desktop studies against the absolute and potential constraints identified, and then evaluate their carrying capacity against relevant environmental and other statutory requirements using the latest available data and modelling techniques. In-depth feasibility study and environmental impact assessment will be carried out for the short-listed sites. All statutory environmental requirements will be met when taking forward any proposed measures. Not only does the science-based approach help assess the environmental acceptability of mariculture activities and operations in a fish farm site, it also assists policy-making and decision-making on the development of the industry.

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Country Paper 10: Integrated multi-trophic aquaculture of fish, bivalves and seaweed in Sanggou Bay

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Abstract

With the rapid development of finfish cage mariculture, the discharge of dissolved and solid wastes from the cages to the environment causes serious problems of coastal eutrophication. This can consequently lead to red and green tides and the deterioration of marine coasts. Integrated multi-trophic aquaculture (IMTA) has been proposed as a potential solution to such environmental problems and at the same time it is a proven means of seafood production. IMTA has become a popular term, which refers to the integration of species from different trophic positions in the water, i.e. where the output (waste) of one species is ultilized by other co-inhabiting species. In this paper, we report a specific farming technique and practice of integrated multi-trophic mariculture finfish, bivalves and seaweed in Sanggou Bay, on the northern coast of China. In this IMTA system, bivalves function as a filter to remove the suspended particulate organic materials that originate from fish faeces, small size residual feed and phytoplankton. Seaweed is used to remove and transform dissolved inorganic nutrients from effluents of both finfish and bivalves and in return provide dissolved oxygen (DO) to the finfish and bivalves. This case study includes three parts: (1) description of the sustainable intensification of aquaculture (SIA) practices; (2) lessons learned; and (3) the way forward. In the first part, we describe the IMTA practice involving fish, seaweed and bivalves, the process and impact. This includes: (1) assessment of mass balance for sea bass *(Lateolabrax japonicas)* and black rock fish (*Sebastodes fuscescens*) growth cycle, which includes the waste particulates (faeces) and metabolic byproducts (nitrogen excretion, oxygen consumption); (2) appropriate integrated species selection (bivalves should be able to utilize the waste particulates, and be of the type of bivalve that has higher efficiency); (3) for the seaweed, it is important to consider the coupling of the culture period with other IMTA species, because seaweed growth has great seasonal characteristics; (4) optimal co-culture densities of fish, seaweed and bivalves, which are based on the efficiency of wastes removal; (5) distribution of cage and long-line *in situ*, which depends on the waste dispersion and environmental conditions. The actual demonstration results such as the growth of bivalves and seaweed in IMTA and the control area, the quality of products and environmental benefits are reported.

Introduction

Mariculture in China has grown rapidly over the past few decades, with a production increase from 1.2 million tonnes in 1980 to 15.5 million tonnes in 2011 (FAO, 2012). Molluscs contribute nearly 80 percent to the total mariculture production. With intensification of aquaculture systems and the increase in the number of species farmed in China, the relative quantity of high trophic level species increased rapidly. From 1999 to 2008, the production ratio of marine fed fish and crustaceans to total mariculture production increased from 6.2 percent to 12.7 percent. At present, aquaculture in China is encountering challenges related to epidemic outbreaks, limited availability of improved varieties of farmed species, and environmental deterioration. Evaluating aquaculture sustainability indicates that the main constraint for future development is environmental deterioration, increased use of energy and fishmeal.

With the intensification of mariculture, the impact of this industry on the ecosystem has become serious, and consequently, the degraded environment has resulted in higher mortality of mariculture organisms. Waste nutrients discharged from mariculture activities (Cui *et al.,* 2005) along the Yellow Sea and Bohai Bay were found to consist of approximately 6 010 tonnes nitrogen (N) and 924 tonnes phosphorus (P). These discharges are equivalent to the 2.8 percent and 5.3 percent of total land-sourced pollutants in these areas, for nitrogen and phosphorous respectively. This indicates that nutrient discharges by mariculture have reached a noticeable level in certain regions of China. For example, in the cage culture area of Sandu Bay, Fujian province, the average content of inorganic nitrogen and phosphorous was 0.324 mg/l to 0.368 mg/l and 0.034 mg/l to 0.035 mg/l, which was higher than the second category defined for the national sea water standard (Lin, 2014).

The mariculture industry worldwide is searching for methods to support further growth of aquaculture production in a sustainable manner. Molluscs form their carbonate shells and seaweed absorbs inorganic nutrients from water, and this production thereby represents a clean industry and one that can sequester carbon (Zhang *et al.,* 2005, Tang, 2010). The important aim is to develop an ecological approach to industrialized open water aquaculture that will result in low carbon emission and low environmental impact and help to meet the increasing demand for aquatic products. Integrated multi-trophic aquaculture (IMTA) refers to the combination of different trophic levels in the same culture system with the intention of increasing sustainability and profitability through reduction of the environmental impact of wastes. These wastes from higher trophic levels are reutilized by lower trophic levels (Lefebvre *et al*., 2000; Chopin *et al*., 2001) and encourage diversification as a measure to reduce economic risks and to increase competitiveness (Barrington *et al*., 2009). In short, IMTA combines the cultivation of fed aquaculture species (mainly finfish) and/or inorganic extractive aquaculture species (seaweed and bivalves) in equilibrium with the site conditions, economic balance, social interest, and environmental concerns (Troell *et al*., 2009). Integrated farming is one of the best paradigms of the ecosystem approach to aquaculture with advantages of incremental carrying capacity, bioremediation, diversified products and prevention of diseases. IMTA is attracting interest globally.

China has a long history of ecological mariculture/polyculture, very similar to IMTA. Now, integrated aquaculture is considered one of the most important alternatives for China's aquaculture to develop rapidly and sustainably (Fang and Zhang, 2015).

1. Detailed description of the successful practices

1.1 IMTA of fish, bivalves and seaweed in Sanggou Bay

Marine fish cage farming releases organic and inorganic wastes into the environment in the form of excess unconsumed feed, faeces and other excretory products. In order to reduce such effects, IMTA production systems, where extractive species (bivalves, seaweed) are cultured simultaneously with fed species (fish) so as to assimilate the waste resources and reduce the pressure on the environment, have been adopted in Sanggou Bay. In such systems bivalves function as a filter to remove the suspended particulate organic materials that originate from fish faeces, small size residual feed and phytoplankton. Seaweed is used to remove and transform dissolved inorganic nutrients from the effluents released from both finfish and bivalves and in return provides dissolved oxygen (DO) to the finfish and bivalves. A schematic diagram of this process is depicted in Figure 1.

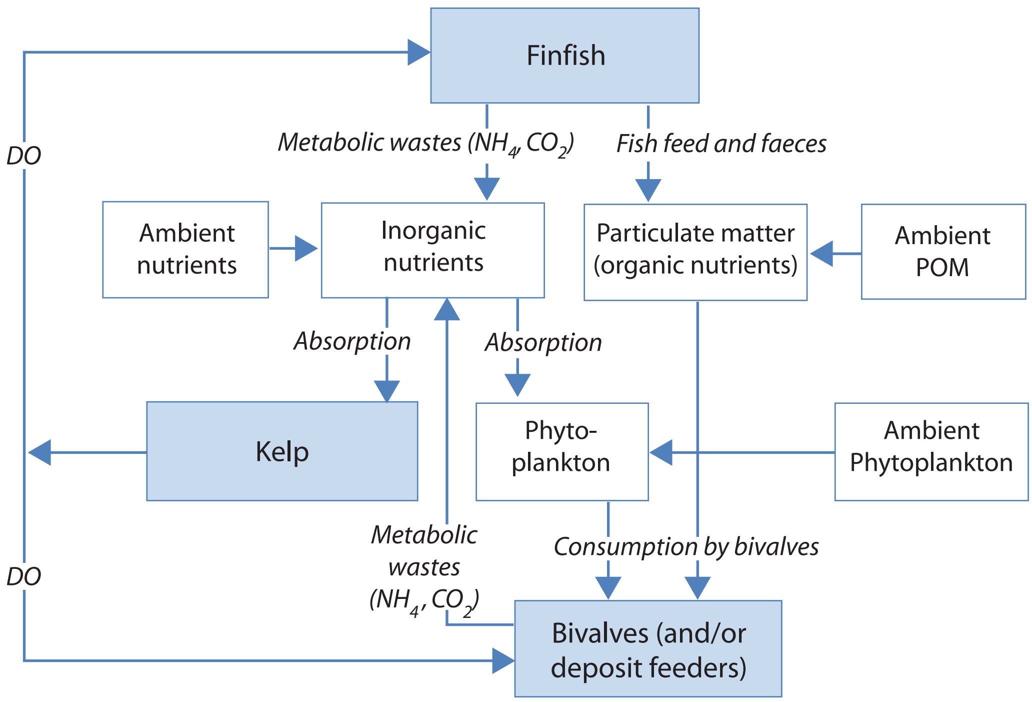

Figure 1 Schematic diagram of IMTA involving finfish, seaweed and bivalves

1.2 Finfish cage culture

The traditional cage size was 3 m × 3 m to 5 m × 5 m in square shape with net depth of 3 m to 5 m and 26–92 cages were interconnected and located along the northern coast of Sanggou Bay. Sea bass, *Lateolabrax japonicas,* and black rock fish, *Sebastodes fuscescens,* (71.82 percent and 28.18 percent respectively) were the main species cultured in these cages. In each cage, 500 individuals were cultured with an annual production of about 125 kg per cage. Fishes were fed with iced trash fish (*Engraulis japonicus*, *Ammodytes personatus*, *etc.*) and cultured during April to January.

1.3 Longline rafts

Raft ropes are made of polyethylene synthetic materials of 22 mm diameter. Floats are made of propylene synthetic plastic material, and the number on each raft was adjusted according to the weight of the cultured species. The main direction of the longline raft was held along the current, which was located downstream of the finfish cages. For each cultivation unit, there were four longline rafts. The length of one longline is 80 m to 100 m, the distance between two longline rafts was about 5 m. Therefore, the total area for each cultivation unit was about 1 600 m^2.

For bivalve culture, 50 lantern nets were hung and kept at 3 m depth for each longline. For the lantern net, there were 10 to 15 levels per lantern net and these changed according to the water depth. At each level, 30 to 40 individual bivalves were cultivated. The culture period was usually from April to March.

For seaweed culture, kelp, *Saccharina japonica* (previously *Laminaria japonica*), was hung vertically. There were 100 ropes for each longline raft and about 35 kelp individuals cultured on each rope. Totally, about 14 000 individuals of *Laminaria* were cultivated at each cultivation unit. Kelp was cultivated from November and harvested during June of the following year. From July to October, red seaweed, *Gracilaria lemaneiformis* (Rhodophyta), was cultured instead of kelp, but the culture model was the same.

2. Process

Chinese traditional cage culture, which is usually located in nearshore areas with low current, is associated with serious environmental problems such as eutrophication, low DO and transparency, fish growth retardation (Xu and Qian, 2004) because of the accumulation of nutrients. To reduce the organic pollution, integrating the filter-feeding bivalves (e.g. mussels, oysters, scallops) and seaweed with fish farms has been advocated as an effective strategy to alleviate the negative impact of waste loadings on the environment (Chopin *et al.,* 2001; Neori *et al.,* 2007). China's successful technique on longline bivalves and seaweed culture and richness in cultivable marine species has made it easy to implement IMTA and it is accepted easily by farmers. China also has a long history of polyculture, which is the co-culture of various species in practical terms mostly carried out without regard to trophic level. IMTA is a kind of specialized polyculture. In order to develop the IMTA model, we carried out research on those aspects addressed below.

2.1 Appropriate integrated species selection

- **Laboratory experiments**

Species selection should be based on habitat specificity, environmental and oceanographic conditions, complementary ecosystem functions and growth rate etc. Bivalve selection was from the typical maricultural species in Northern China. Therefore, the filter-feeding ability and absorption efficiency (AE) of the waste particles and their growth rates were the main parameters of research investigation to develop the IMTA system. As gill structure, physiological and ecological characteristics are different, different species of bivalves have different feeding behaviours. Statistical methods were used to study the feeding behaviour of five species of bivalves. Their feeding behaviour on different food, including flounder (*Paralichthys oolivaceus*) faeces, residual feed and deposition was studied, so as to analyze the potential of IMTA based on filtering feed bivalves. The five bivalve species are clam, *Ruditapes philippinarum*, oyster, *Crassostrea gigas*, scallop, *Chlamys farreri*, *Patinopecteny essoensis* and blue mussel, *Mytilus edulis*. Results showed that the five species of bivalves could assimilate fish faeces, residual feed and deposition. However, different species exhibited different feeding behaviours. Ingestion rates of oyster, clam and scallop were significantly higher than the other two species (ANOVA, $p < 0.01$). Absorption efficiency of residual feed was not significantly different, but there were significant differences among faeces and deposits of the five species. There was a positive correlation between AE and organic content and a significant linear relationship between absorption rate (AR) and particulate organic matter (POM). Total particulate matter (TPM) threshold for pseudo-faeces production of oyster, scallop and clam was 26.24 mg L^{-1}, 21.64 mg L^{-1}, 27.00 mg L^{-1}, respectively, and the five species of bivalves could regulate food intake by pseudo-faeces production. In the IMTA model, clam, *Ruditapes philippinarum*, oyster, *Crassostrea gigas,* and scallop, *Chlamys farreri,* are relatively good candidate species (Zhang *et al*., 2013).

- **Field experiments**

Growth and origin of food sources of the Pacific oyster (*Crassostrea gigas*) integrated with sea bass (*Lateolabrax japonicas*) and Chinese scallop *(Chlamys farreri)* integrated with *Paralichthy solivaceus* culture were studied in northern Sanggou Bay, during a field study from April to October (Jiang *et al.* 2013) and May to August (Chen, 2015), respectively. Both shell and tissue growth of the oysters and scallops were higher – 30 percent to 40 percent and 10 percent to 32 percent, respectively at the fish farming site compared to a control site where fish farming was absent. Furthermore, stable isotope signatures in oyster and scallop tissue showed enriched values at the farming site, indicating that the difference in growth performance between the cage and the control area was because of the utilization of organic matter derived from fish aquaculture.

2.2 Complementing the periods of culture of different species

Most cultured species, such as seaweed in China, are temperate eurythermic species. *Laminaria,* however, is a boreal species and only survives in the cold season. It is cultured during November to June. In summer, kelp cannot survive. Therefore, tropical species *Gracilaria* was selected in the IMTA and was cultured during June to November. Combining cultures of tropical and boreal species in different seasons according to temperature preferences could make full use of the time and nutrients released from finfish cage and yield higher total production of the IMTA system. Because it is an important food component of sea cucumber, the price of seaweed *Sargassum thunbergii* is higher than other seaweed. Selecting high value species is one of the ways to improve the benefit of IMTA and economic benefits are one of the key points for acceptance of IMTA by the farmers. Therefore, the longline culture technique of *Sargassum thunbergii* was studied.

2.3 Optimum co-culture densities of fish, seaweed and bivalves

To evaluate the optimum densities for simultaneous culture of finfish and seaweed, a field study was conducted at a farming site in northern Sanggou Bay (Ge *et al.,* 2007). Sea bass *(Lateolabrax japonicus* – 72 percent) and black rock fish (*Sebastodes fuscescens* – 28 percent) cultures were fed iced trash fish. The production period lasted from April to January with an annual production of 3 250 kg for this site (5.6 km^{-2}). Based on the biological characteristics, *Laminaria* and *Gracilaria* were selected as extractive species. These two seaweed species were cultured sequentially throughout the seasons with kelp from December to May (winter/spring) and *Gracilaria* from June to November (summer/autumn). The yield of seaweed was 5.6 kg W_w/m^2 and 3 kg W_w/m^2 for *Laminaria* and *Gracilaria* respectively. Nitrogen was selected as the parameter to balance the seaweed absorption and fish production. Assuming the nitrogen in feed residue and fish faeces could be converted to dissolved inorganic nitrogen completely (100 percent) (including direct conversion and microbial degradation), then the nitrogen balance equation can be represented as follows $N_{seaweed} = N_{fish\ excretion} + N_{feed\ residue} + N_{fish\ faeces}$. Where feed residue and faeces are 1.5 and 0.1 times the nitrogen excretion (Ning and Hu, 2005). Nitrogen quantities released by the combined fish culture of sea bass and rockfish are 510 kg N and 5 874 kg N in winter/spring and summer/autumn, respectively. Nitrogen content of *Laminaria* and *Gracilaria* was 1.34 percent (dry weight) and 2.70 percent (dry weight), respectively. To balance the nitrogen release, the estimated optimum co-culture proportion is 10.44 for *Laminaria* in winter/spring and 11.12 for *Gracilaria* in summer/autumn, where fish is expressed in kg wet weight (kg W_w) and seaweed in kg dry weight (kg W_d).

For the bivalves, in the present study (Jiang *et al.,* 2012), assimilation efficiency of the oysters for fish aquaculture-derived organic matter was estimated at 54 percent (10 percent waste feed and 44 percent fish faeces). For example, if 42 percent of the total solid nutrient loads from fish cages are within the suitable size range (Elberizon *et al.,* 1998), the oysters will theoretically be able to recover approximately 23 percent of the total particulate organic matter released from fish cages. The assimilation efficiency of scallops for fish aquaculture-derived organic matter was estimated at 26 percent (Chen, 2015). The scallops will theoretically recover nearly 10 percent of the total particulate organic matter released from fish cages.

2.4 Distribution of cage and longline *in situ* area

The distribution of cage and longline should depend on the waste dispersion. Distribution of the waste particles has a close relationship with the characteristic of the waste particles (inorganic content, particle size etc.) and the environmental condition (e.g. current, coefficient of friction of sediment and resuspension, water depth). Usually the proportion of waste particles to total organic carbon in the sediment decreased with increasing distance from the fish cages. Biomarker techniques such as stable isotope and fatty acid signature are used to trace the waste particle dispersion (Yokoyama *et al*., 2006), and it was found that as distance from the fish cages increased the waste particles decreased exponentially. Another kind of food source for bivalves is phytoplankton. DIN (sum of ammonia, nitrate and nitrite) released from fish cage will stimulate the growth of phytoplankton and then provide more food for bivalves. Therefore, the IMTA system is complex and it is difficult to give exact ratios and distributions of finfish, bivalves and seaweed. A mathematical model should be developed to give theoretical guidance.

3. Impact created

Sanggou Bay is located in Shandong Province of the People's Republic of China. With an area of 144 km^2 it has been used for aquaculture for more than 20 years (Guo *et al*., 1999). The main cultivation method is longline culture and cultivated species include seaweed (*Saccharina japonica*), oyster (*Crassostrea gigas*) and scallop (*Chlamys farreri*). In the northern and southern area of Sanggou Bay, there are several finfish cages.

3.1 Production efficiency

A significant growth in shell length and soft tissue weight of bivalve were obtained in the cage area. The growth of seaweed in the cage area was found to be significant. The finfish, seaweed and bivalve IMTA could improve the production of seaweed and bivalves, and the growth of fish as well. From our experiments, we calculated that the production of seaweed and bivalves in the cage area could increase by 30 percent, and 16 percent, respectively, as compared to the control area (see Figures 2, 3, and 4 for the site location and Figures 5 and 6 for data on growth of the cultured bivalve and seaweed).

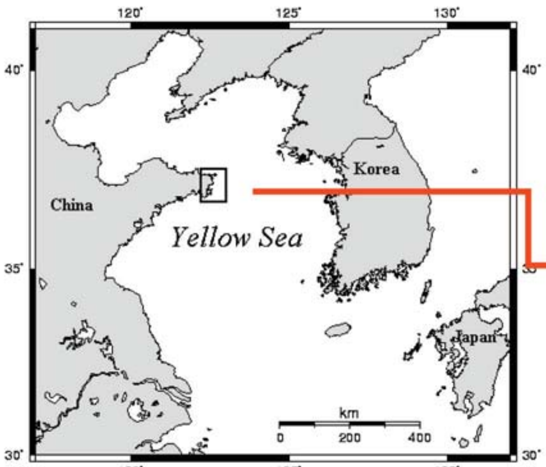

Figure 2 The location and mariculture distribution of Sanggou Bay, China

Figure 3 The location of IMTA – Sanggou Bay, China

Figure 4 IMTA in Sanggou Bay, China: finfish, plus seaweed plus bivalves

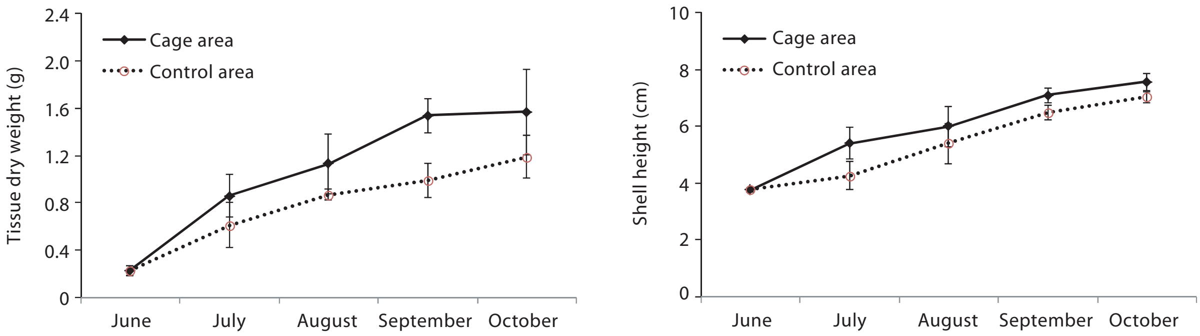

Figure 5 Growth in tissue dry weight of experimental scallop

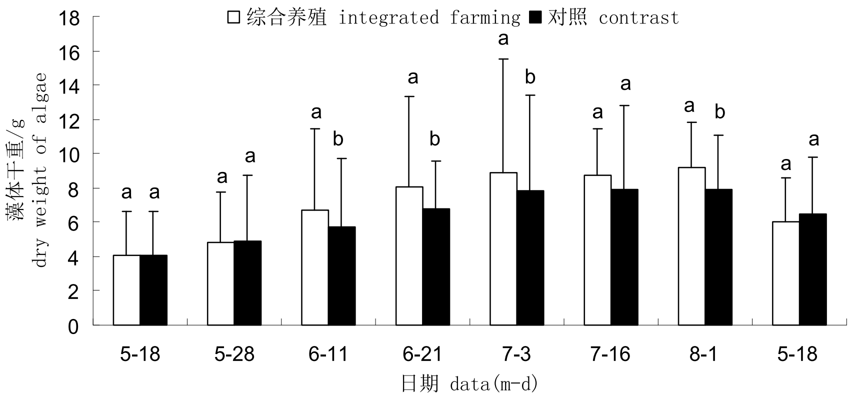

Figure 6 Growth in dry weight of experimental seaweed

3.2 Environmental benefits

The MOM-B system (Modelling-On growing fish farms-Monitoring), which was developed to control the impact of organic waste from marine fish farms in Norway, was introduced to Sanggou Bay to assess the impact of large-scale mariculture on the environment. The Sanggou Bay has sustained aquaculture for over 20 years and the benthic environment is still not severely impacted (Zhang *et al*., 2009).

3.3 Food quality

Feeding the wastes of one species to another also carries the risk of cross-contamination. It was reported that mussel and kelp growing adjacent to Atlantic salmon cages in the Bay of Fundy has been monitored since 2001 for contamination by medicines, heavy metals, arsenic, PCBs and pesticides. Concentrations are consistently either non-detectable or well below regulatory limits established by the Canadian Food Inspection Agency, the United States Food and Drug Administration and European Community Directives (Haya *et al*., 2004).

In China, the small iced-fresh fish *Engraulis japonica* and *Ammodytes personatus* are the feed for mariculture fish. The influence of drugs, heavy metals, etc. does not exist in this IMTA system. The product quality of bivalves and seaweed is not influenced by finfish in cages. On the contrary, since the particle organic materials contain high unsaturated fatty acids, the bivalves in the cage area contain higher unsaturated fatty acids than the control area. This enhances the nutritive value of the bivalves raised in the IMTA system.

Our results showed that the bivalves in the cage area maintain high meat weight and condition index (meat to shell ratio) that not only increases the production of bivalves, but also increases the quality of their flesh.

Table 1 The fatty acids component of oyster in cage and control areas

	Initial data	Cage area	Control area
Saturated fatty acids			
C140	4.66	5	3.94
C160	21.915	20.54	20.92
C180	3.6	3.11	3.07
C170	2.415	1.06	1.55
Mono-unsaturated fatty acids			
C161	4.46	3.92	3.16
C181 n-9	4.105	8.28	5.9
C181 n-7	5.66	4.69	4.44
Multi-unsaturated fatty acids			
C182 n-6	2.735	2.28	1.94
C183 n-6	2.645	2.18	2.55
C205 n-3 (EPA)	17.015	17.27	14.89
C226 n-3 (DHA)	14.385	16.7	15.5
Saturated fatty acids	**32.59**	**29.71**	**29.48**
Mono-unsaturated fatty acids	**14.23**	**16.89**	**13.5**
Multi-unsaturated fatty acids	**36.78**	**38.49**	**34.88**

4. Lessons learned

4.1 Successful experience

A multiculture system is complicated and strongly dependent on the local environment. The fish-bivalves-seaweed multiculture system started from laboratory experiments and with continuous effort it developed into field experiments and has subsequently proven effective when adopted by farmers. With local fish farmers and industries participating in the practice of the integrated multitrophic culture system, it has been gradually accepted by aquaculture industries in the coastal regions.

In order to improve the knowledge of farmers, several workshops and training courses focusing on IMTA have been conducted in Shandong, Liaoning and other provinces. During the courses, IMTA aquaculture technology and new production model, aquatic product quality and safety were covered. The IMTA was presented as having a high potential for sustainable mariculture. Recommendations were made regarding the culture of IMTA in Shandong province. The participants showed great interest in the workshop. They not only understood the concept of IMTA, but also improved their ability to understand the theory and technique of IMTA.

4.2 Gaps to fill

Nutrient recovery efficiency is a function of technology, harvest schedule, management, spatial configuration, production, species selection, trophic level, biomass ratios, natural food availability, particle size, digestibility, season, light, temperature, and water flow (Neori *et al*., 2004; Troell *et al*., 2003; Mazzola and Sara, 2001). Since these factors vary significantly by site and region, recovery efficiency also varies. So, it is difficult to estimate the nutrient recovery efficiency at present.

The distribution of longline around finfish cages will depend on the waste mass and distance of waste dispersion. However, the waste dispersion varies according to the particle characteristics such particle size, weight, organic content etc. and the environmental conditions such as current velocity, direction, sediment characteristics, re-suspended rate and so on.

4.3 Potential for further improvement

The ability of bivalves to act as an appropriate biofilter of finfish wastes in IMTA systems depends on the suitability of farm organic output as a food source for the bivalves (Handa *et al*., 2012; Cranford *et al*., 2013). Particle size is an important parameter in bivalve feeding. In China, iced-fresh small fish, not artificial feed, usually is used as food for finfish in cages. Therefore, the waste particle size from residual diet varies according to environmental conditions. Suspended organic particles in the water may come from re-suspension of the decaying residual diet. The distribution of particles in the waterbody should be investigated using a mathematical model in the future. In Sanggou Bay, a multi-species model for shellfish and kelp polyculture was developed, integrating a bay-scale ecological simulation with individual-based modelling of scallops and oysters, and scales up the individual processes for the target species by means of a multi-cohort population dynamics model (Nunes *et al*., 2003). A model that simulates the dispersion and bottom deposition of organic particles from fish farms is being worked on now. Based on the above theoretical models, a model for IMTA of finfish (*Sebastodes fuscescens)*, with longline culture of bivalves, namely scallop, *Chlamys farreri*, oyster, *Crassostrea gigas*, and seaweed, *Laminaria* and *Gracilaria* is under construction and the results are expected in the near future. Other deposit feeders (e.g. polychaetes, sea cucumbers, sea urchins) can be included to feed on other size ranges in order to achieve maximum nutrient recovery efficiency in the finfish based IMTA systems.

5. The way forward

- With the population growing, intensification of mariculture is necessary to meet the rising demand for seafood products. Maintaining low carbon emissions and sustainable development with increases in production are the key issues that have to be addressed.
- The Asia-Pacific region is a core area of global aquaculture accounting for 85 percent of the global aquaculture production. With intensive cage culture, a lot of bait, faeces, and biological debris will find its way into the water and sediment. In the Asia-Pacific region, cage culture usually is sited in the nearshore, shallow, sheltered areas and the cultured species are fed fresh small "trash" fish. Therefore, food waste pollution is serious and could affect the sustainable development of cage aquaculture. Not only China, but the mariculture industry worldwide is searching for sustainable methods and policy programmes are focussed on an ecosystem approach to aquaculture (EAA), of which implementation of IMTA is one potential solution (Chopin *et al*., 2012). Although finfish, seaweed and bivalve IMTA is still in its developing stages, it shows consistent growth.

This IMTA technique originated from a simple farming model, and hence it can be realized without any modification of culture equipment and it is easy to adopt.

- The global demand for seaweed products is rising and seaweed farming also has many advantages, including low investment risk, convenient management and restoration of habitat, absorbtion of carbon dioxide and so on. The IMTA could improve the products of seaweed that could benefit the economy and ecology.
- A multiculture system is complicated and strongly dependent on the local environment. It needs to make adjustments according to local conditions. It could take some time to be adopted by farmers. For example in Canada, there were no IMTA sites in Fundy Bay in 2001. Nine years later, eight of the 96 finfish sites in southwestern New Brunswick practice salmon or cod/mussel/kelp production. Strengthening the promotion and training will help IMTA to be accepted by more people. The IMTA system has lower financial risk than the traditional monoculture system for the fish farmers and industries, and the recycling of organic matters in the waterbody can relieve the pressure on the local ecosystem. With scientific determination of cultivation amount and species, this IMTA system can help the development of many coastal aquaculture regions in a sustainable way and could be used in other countries and regions.

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Country Paper 11: Sustainable milkfish production in marine fish cages through strong government support and effective public-private partnerships: a case study from Panabo City Mariculture Park in Davao del Norte, Philippines

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Abstract

This case study presents the successful practice of sustainable intensification of milkfish aquaculture in marine fish cages under semi-intensive grow-out conditions in the Panabo City Mariculture Park (PCMP) in Davao del Norte, Philippines. Established in 2006, PCMP became operational through the promulgation of a City Ordinance declaring 1 075 hectares of municipal waters in Panabo City as a Mariculture Development Zone/Park. The operations of PCMP were so successful that in just five years it became the third largest among the 63 operational MPs in the Philippines during 2011, with 86 private investors-locators operating a total of 322 units of cages. At present, a total of 372 units of fish cages are operating in the mariculture park (MP). A combination of factors contributed to the successful operation of PCMP, but the success is usually attributed to the effective partnership between the government (both local and national) and the private sector. The Comprehensive MP City Ordinance that governs the PCMP is strictly implemented and includes, among others, the tenurial rights and access to locators. Regulations on distances between cages are strictly enforced and security measures in the total area are jointly undertaken by the government and the locators. The national government, through the Bureau of Fisheries and Aquatic Resources-National Mariculture Center (BFAR-NMC), provides technical support in all aspects from stocking to harvest during the production cycle. BFAR-NMC staff conduct regular periodic sampling of the stocks and compute feeding rates for the stocks which are implemented by the technicians/caretakers. Likewise, BFAR-NMC staff regularly monitor the water quality of the MP and the health status of the stocks. Since it became operational in 2006, the PCMP did not report a single incident of mass fish kill, which indicates that the technical guidelines of MP operations are strictly followed. Workers are trained and organized into groups by BFAR-NMC such as caretakers, cage framers, netters, harvesters, fish processors, and others, and actively participate in discussions related to MP operations to ensure protocols are properly followed. Harvests of stocks are done by skilled workers trained by BFAR-NMC, all done in the "Bagsakan Center" or fish landing area and are well-coordinated. The support facilities in the fish landing area are provided by both the local and national government and the PCMP Producers Association. The operators provide complete data for their operations to BFAR-NMC for record keeping. The strong partnership between the national government through BFAR-NMC, the local government unit, the investors, as well as the acceptance and support from the community for the PCMP is the hallmark of its success.

Introduction

When the Philippine national government embarked on a massive food production programme to feed its fast growing population, increasing production in the fisheries sector, including aquaculture, was one of the focii. One of the strategies to improve aquaculture production was to increase the area for production and establishing mariculture parks (MPs) was considered a viable solution. The MPs were established by the Department of Agriculture-Bureau of Fisheries and Aquatic Resources (DA-BFAR). The objectives were to: (1) provide employment and an alternative source of livelihood for subsistance fisherfolks; and (2) develop skilled and technically capable fisherfolks to support the mariculture industry, among others (Adora, 2010). The first MP was established in 2001 and by 2011, there were 63 MPs established and operating in the country. Because of the high market demand for milkfish and its importance to the country's fish supply, milkfish (*Chanos chanos*) is the main species grown in MPs. Many of the MPs established in the country are operating at a sub-optimal level, and some have been abandoned already. A common problem encountered by the MPs in the country is the excessive proliferation of structures (fish cages) in the area that resulted in overcapacity. This situation, probably results in mass fish kills. In some MPs, fish kills occur every year. This practice threatens the economic viability of the enterprise, degrades the surrounding environment and consequently destroys the sustainability of the operation.

The case of the Panabo City Mariculture Park (PCMP) is unique in the country for several reasons. The relationship among the key players in the industry, namely, (1) the local government unit (LGU) that provides the legal framework and support for the establishment of MPs in their respective areas, (2) the national government through DA-BFAR that provides some of the infrastructure and the technical support in the operations, and (3) the private sector represented by the investors and other providers of ancillary support services, is strong and performing effectively. The successful operations of the PCMP are anchored on the harmonious working relationships among the parties as evidenced by the continuing increase in the number of investors and fish cages in the area. From just three milkfish cages when PCMP was established in 2006, there are at present 372 units of fish cages in this area (Accomplishment Report, 2015). Most importantly, not a single case of mass fish kill has happened in the MP since it was established, a proof that the MP is properly managed. This is a clear case/example of the sustainable intensification of aquaculture (SIA). The layout of the park is shown in Figure 1.

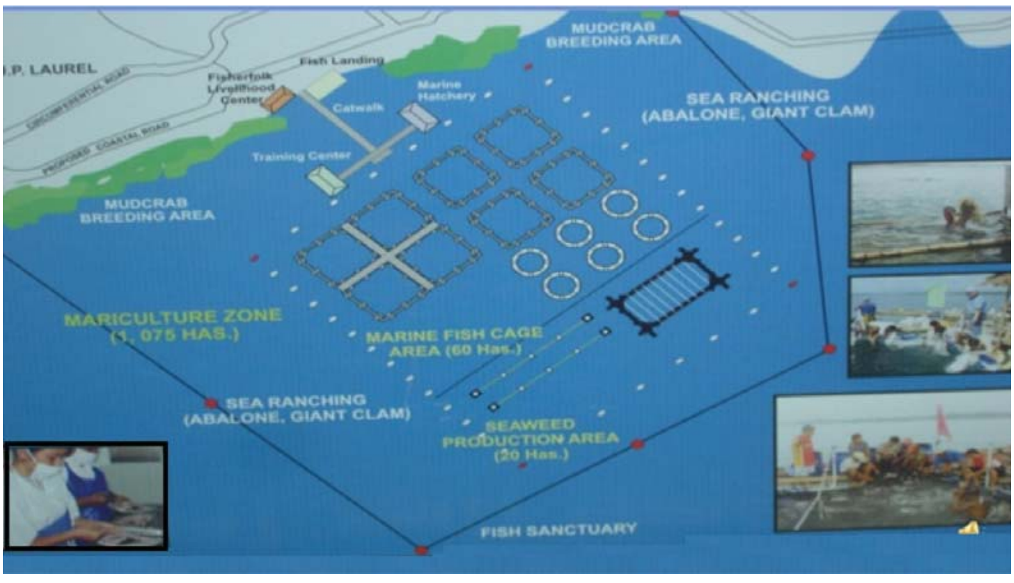

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Figure 1 Layout of Panabo City Mariculture Park

1. Detailed description of the practice

This successful practice of sustainable intensification of aquaculture describes a semi-intensive grow-out culture of milkfish (*Chanos chanos*) in marine fish cages in PCMP in Davao del Norte, Philippines. The unique, strong and harmonious relationships among the key players of the industry namely, the local government unit (LGU) of Panabo City which has the legal jurisdiction over the coastal area where the mariculture park is located; the national government represented by the Bureau of Fisheries and Aquatic Resources (BFAR) through its Regional Office XI in Davao City covering the provinces of Region XI (Davao del Norte, Davao del Sur, Davao Oriental and Compostela Valley), the Provincial Fishery Office in Davao del Norte, and the BFAR-Regional Fisheries Training Center (RFTC) now renamed the National Mariculture Center (NMC); and the private sector that includes the fish cage operators, the feed suppliers, the market players, the banks and other financing institutions, and the providers of the other ancillary support services, as well as the acceptance and support from the community for the PCMP are the hallmark of its success. Strong and dedicated good governance on the part of the leadership of Panabo City LGU, the hands-on, practical, and participatory approach/style of management of BFAR-NMC, and the strong commitment of the private sector to the activity are just some of the key factors that contributed to the success of the SIA in PCMP.

The success of PCMP is so impressive that since its establishment in 2006 when only three cages were in place, it became the third largest MP among the 63 operational MPs in the Philippines in just five years (in 2011), with 86 private investors-locators operating a total of 322 units of cages. Although the area was hit by Typhoon Pablo in 2012 that destroyed lots of the fish cages and made the investors, especially the small players, leave the business bcause of unforeseen financial losses, at present (May 2015), the PCMP has a total of 372 units of fish cages (standard dimension of 10 m x 10 m x 4 m), 314 of these are operated by 76 private investors, 42 cages are operated by fisherfolk families, and 16 cages are BFAR-NMCs technology-demonstration projects. Milkfish production from PCMP has contributed significantly to the Food Security Program of the Philippine Government as it has produced 2 967.75 metric tonnes of milkfish in 2014 valued at PhP 270.6 million (USD6.2 million) (Accomplishment Report, 2014).

1.1 The process

Engaging in economic development with the investors' satisfaction and environmental protection in mind was the main considerations when PCMP was conceptualized and came into operation. Central to this concept is the proper delineation of tasks and responsibilities of the major key players and more importantly the strict implementation of the rules and regulations in the operation of the MP. Since the establishment of the MP in 2006 until the present, it is apparent that what has been agreed by the tripartite parties, has been implemented strictly, and that even with an increasing number of investors and consequently the number of fish cages in the area, operations are profitable. The details of this process are described below. The MP was established after a thorough technical assessment of the candidate areas, done together by BFAR and the LGU of Panabo City. The procedures for getting into milkfish grow-out culture in fish cages in the PCMP were made simple for ease of compliance by the potential investors. After obtaining clearance from BFAR-NMC as to the availability of space in the MP and the proposed location of the fish cages, the potential investor is given a permit by the LGU to operate a specified number of fish cages for milkfish grow-out culture in the MP after paying an annual application fee of PhP1 100.00/cage (USD25). The standard size of the fish cage is 10 m $\times$ 10 m $\times$ 4 m. The issuance of the permit to operate by LGU is given only when there is the prior approval of the application by BFAR-NMC. The LGU, however, requires the payment of a business permit which is equivalent to 0.03 percent of the gross sales/cage/harvest. Once the permit to operate is granted, the technical aspects of operating the fish cages, from cage construction, milkfish fry sourcing, feed supply, technical operations until harvests and marketing are addressed by the investor in close consultation with the provider of the technical information, the BFAR-NMC (Accomplishment Reports 2014, 2015; Anon, 2013).

Although the investor is free to select persons for construction of the fish cages and other related tasks, the BFAR-NMC provides a list of qualified persons in the locality who can do the work for them. These groups of men and women are trained for the specific tasks by BFAR-NMC. After the training, only the persons who passed the set criteria and standards will be included in the recommended list of workers. This pool of skilled workers is available to provide assistance to the potential investors when needed. The categories of skilled workers available are shown in Table 1.

Table 1 Trained pool of skilled workers for the PCMP

Categories	Number of persons
Cage frame makers	8
Net makers	15
Net cleaners	4
Net changers	4
Feed haulers	5
Harvesters	25

All technical assistance during the operation of milkfish grow-out culture in fish cages in the MP is provided by the technical staff of BFAR-NMC at no extra cost to the investors. The stocking density for all cages is standard at 15 000 fingerlings (5 to 6 inches in length)/cage (10 m $\times$ 10 m $\times$ 4 m) or 37.5 pcs/m^3). For proper coordination and for timely provision of technical support to the fish growers, BFAR-NMC makes it mandatory for all investors in the MP to submit data and coordinate all their activities with them. The complete range of technical support such as regular monitoring of growth of the stocks, computation of feeding rates, regular monitoring of environmental parameters and diseases, etc., is provided by BFAR-NMC for the PCMP with the assistance of the caretakers of the fish cages. Water parameters such as temperature, salinity and dissolved oxygen in strategic locations in the MP are monitored daily. Removal of sediments using a locally-manufactured grab sampler is done weekly. Some parameters such as ammonia level, plankton count, determining chemical residues in tissues and microbiological analyses are also monitored regularly. For easy location by the fish farmers, BFAR-NMC has an office just within the premises of the harvesting area (Bagsakan Center). Of particular importance is the regular measurement of the growth (body weight and length) of the stocks and this is done every 15 days. This helps to accurately determine and adjust the feeding rates minimizing the wastage of feeds and saving on high feed cost, which is about 60 percent to 70 percent of the total production cost in fish cages. Furthermore, the wastage of feeds because of overfeeding contributes largely to the degradation of the water quality of the surrounding environment that will most likely cause mass fish kills. The big investors do the growth monitoring themselves but the small investors and the fisherfolk operators avail of the technical assistance provided by BFAR-NMC. This is the reason why BFAR-NMC requires all fish cage operators to coordinate with them during stocking and submit important pertinent data related to the stocks, especially the date of stocking.

BFAR-NMC likewise conducts a weekly meeting with all the fish cage caretakers in the Bagsakan Center to discuss the current FCRs of their stocks. Cage caretakers whose fish cages are showing high FCRs are encouraged to attend. All cage caretakers and feeders are warned of the changes in the FCR of their stocks and reminded of the implications it will have for the costs of the operation and the feed wastage and consequently the pollution to the surrounding environment. An annual free refresher course for fish cage caretakers to update them with new technologies on the milkfish cage culture system is provided. Because of the regular monitoring of the growth of the stocks, scheduling of the harvests can be planned. The harvest of stocks is likewise scheduled by BFAR-NMC in close coordination with the owners of the fish cages, and after the owner and the buyer have agreed on the terms of the harvest and sale. All harvests are brought to the Bagsakan Center, which is provided by the national government through BFAR. The Bagsakan Center is also provided with post-harvest facilities. The volume of harvest is regulated so as not to flood the market with an excess supply of milkfish that can lead to lower prices. Harvest is scheduled daily with an average of two cages/day and a maximum of four cages/day. A cage can produce five to six tonnes of milkfish (average BW of 400 g) during harvest. Scheduling of the harvest is done as early as one month before the actual date of harvest. For new investors in the PCMP, the BFAR-NMC can help establish market linkages as well since they maintain a list of potential buyers. Negotiations with the buyers regarding the method of payment and the buying price are left solely to the cage owners and the buyers.

Law enforcement and the maintenance of security for the entire area of the PCMP is very important as well. Whereas the big investors can arrange security for their cages by themselves, the LGU provides six persons for law enforcement for the small operators. The three barangays where the PCMP is located provide two persons/barangay as part of the law enforcement team. The patrol boat is provided by the LGU and BFAR-NMC provides the communication equipment for the guards such as radios. The LGU's maritime police and the coastguard are also members of the Task Force and are on stand-by.

The participation of the private sector in providing the ancilliary support services is very much visible. The feed companies provide storage vans for the feeds in the Bagsakan Center for the fish cage operators. The supply of milkfish fry and fingerlings for stocking in cages are provided by milkfish hatcheries and several fishpond operators are producing milkfish fingerlings solely for the use of the operators in the MP. Some financial institutions are providing soft loans as well for the fisherfolk to engage in this kind of business. The necessary component businesses for the successful operation of milkfish grow-out culture in fish cages are all there.

As is evident, operating a fish cage in the PCMP is very easy for a potential investor since the LGU has simplified the process of granting the permit to operate. The success of the cage operation is likewise guaranteed by the technical assistance provided by BFAR-NMC in all aspects of the cage operations and the full support provided by the private sector in the other remaining important services. BFAR-NMC now has been given the mandate by the national government to evaluate the operations of the various MPs all over the country and recommend measures how they can be improved with the long-term sustainability of the industry as the major consideration.

2. Impact created

2.1 Contribution to food security

The sustainable successful operation and the improved production efficiency of milkfish in fish cages in the PCMP has indeed contributed to the national government's thrusts of improving food security. Milkfish production in PCMP over the years has reached 12 079.14 metric tonnes (Table 2).

Table 2. Milkfish production in PCMP from 2006–2014

Year	Number of cages	Production (Metric tonnes)	Value (PhP)	Value (USD)
2006	3	2.90	235 837.00	5 359.90
2007	10	23.01	1 894 516.75	43 057.20
2008	171	314.42	27 011 241.50	613 891.85
2009	323	1 919.00	160 459 193.02	3 646 799.84
2010	350	1 803.95	155 961 144.44	3 544 571.45
2011	294	1 517.55	132 472 826.69	3 010 746.05
2012	349	1 683.04	144 418 591.35	3 282 240.70
2013	323	1 848,42	161 964 379.06	3 681 008.61
2014	332	2 967.75	270 622 494.71	6 150 511.23
Total		12 079.14	1 055 040 260.62	23 978 180.77

USD1 = PhP44

2.2 Contribution to job employment opportunities

A substantial number of local people have been employed in the PCMP. Job opportunities are available as fish cage caretakers, in construction and maintenance, in mooring systems, in stocking, in harvesting, handling, marketing, as service boat operators, security staff, in ice storage and fish processing. About 261 fisherfolks and local residents are currently directly employed in various jobs in the PCMP with an income worth PhP551.2 million (USD12.5 million) in 2014.

2.3 Contribution to investment promotion

An active public-private partnership is established in the PCMP. There is a special financing programme with low interest rates that allows local people to engage in milkfish cage culture. These are offered by financing institutions such as the Land Bank of the Philippines Davao through some local banks (e.g. TruBank). The milkfish fry and fingerlings suppliers are increasing in number. There are 59 co-operators producing milkfish fingerlings in 583 hectares of fishponds. The dominant feed companies are the ones that provide good quality feeds based on the FCR. Other investment opportunities are processing for value adding. At present there are three women's groups, mostly housewives and out of school youth, who are doing various activities in support of the PCMP. The Cagangohan Women's Association of Panabo City, with 20 members, is engaged in milkfish cage production, milkfish processing, direct selling of fresh and processed milkfish and other value added products. The Bangus (milkfish) Processors Women's Association with 16 members is producing dried and smoked milkfish. The third group is the Organic Bangus (milkfish) Processors Women's Association with 14 members that is producing dried, smoked, bottled and boneless organic bangus (BFAR-NMC, 2015).

3. Lessons learned

3.1 Successful experiences

As mentioned above, the good working relationships among the three parties involved in the operation of the PCMP is among are key factors in the success of the operation. These key players fully understand their respective roles and responsibilities and more importantly respect each other. In addition, they execute their respective functions and responsibilities in the PCMP strictly. It must be noted that these parties are also present in many of the MPs in the country but somehow the LGU, who has the legal jurisdiction of the area, exerts more influence in the management of the area and somehow there is not much coordination between the parties.

3.2 Potential for further improvement and gaps to fill

The potential for the industry to improve further is immense considering that the technology to grow milkfish is there and there is a ready market. There is however a need to prepare plans to address some issues that are currently experienced by the industry. Considering the increasing number of fish cage operators in the PCMP and consequently in the country, the provision of additional support is critical. The supply of milkfish fry for the fingerling production is sometimes limiting. The establishment of more milkfish hatcheries is therefore required. Milkfish fingerlings for stocking in the fish cages are sometimes not available. Since milkfish fingerlings grow best in brackishwater ponds, more fishpond operators are encouraged to focus their operation in milkfish fingerling production to supply the needs of the milkfish mariculture industry. Considering the high costs of the feeds, reducing them will definitely be welcomed by the growers. Since milkfish feeds on algae in the natural environment, it may accept artificial feeds that are low in or have no fishmeal content. This will definitely be better for the long-term sustainability of the industry. The provision of post-harvest facilities near the MPs is likewise an advantage.

3.3 Prospects for dissemination and the way forward

Given the present technology of milkfish production in fish cages and the successful manner of operating the PCMP, the national government may use the model of PCMP in running the other MPs in the country, especially those that become problematic by causing environmental degradation. Elevating the status of the then BFAR-RFTC to now BFAR-NMC is a step in this direction. After becoming a national centre, BFAR-NMC has in fact started evaluating the other MPs in the country. Replicating the PCMP model in other areas in the country and in the region may not be difficult since the key factors responsible for its successful operation are already clearly identified. It will just be a matter of strictly implementing the model and with the right people implementing it.

The milkfish grow-out technology in fish cages being practiced in PCMP is easy to disseminate and replicate in other places provided that the environmental and technical considerations are met. Cage dimensions are uniform at 10 m × 10 m × 4 m with distances of 5 m to 10 m between cages and 20 m between culturists/investors. The size of milkfish fingerlings at stocking is about 5 inches to 6 inches in length and roughly about 50 g in body weight (BW). The stocking density is uniform in all the cages at 15 000 pieces per cage (total volume of 400 m^3) or 15 kg/m^3 to 18 kg/m^3 at harvest. The stocks are fed mainly milkfish artificial feeds produced by commercial feed companies. During the four-month culture period to reach the marketable size of 400 g to 500 g, the stocks are fed three types of feeds, namely, starter crumble feeds, grower feeds and finisher feeds given during the first until the fourth month, in that order. The feeding rate, which is computed based on the growth of the stocks measured every two weeks, decreases as the culture period progresses, from 6 percent of BW during the first month of culture, to 5 percent during the second month, 4 percent during the third month and 3 percent during the fourth month until harvest. The feeds are given six or seven times in a day starting at about 07.00 hours. The current feed conversion ratio (FCR) ranges from 1.9 to 2.2. The feeds have decreasing protein content, 31 percent crude protein (CP) for starter feeds, 29 percent CP for grower feeds and 27 percent CP for finisher feeds. During the early years of the operations of PCMP, the feeds used were mainly sinking feeds but now the feeds are mainly floating feeds and slow-sinking type. During the four months culture period, changing of nets is done only once – usually after the second month of culture.

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Country Paper 12: Development and dissemination of closed (semi-closed) intensive shrimp farming system in Thailand

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Abstract

Shrimp farming in Thailand had been developed from a traditionally extensive system to an intensive farming system through the use of good management practices combined with new technologies. In 1987, shrimp farming in Thailand started with the culture of *Penaeus monodon* and commercially developed into intensive shrimp farming in 2000. The production during this period increased from 23 566 tonnes to 309 862 tonnes. However, the outbreak of monodon slow growth syndrome (MSGS) in 2002 ended the era of large-scale farming *of P. monodon* because of the potential risks of loss from intensive farming. Whiteleg shrimp *(Litopenaeus vannamei*) was introduced during 2003-2004 for culture as an alternative to *P. monodon* and showed a good adaptation to the tropical climate and suited to the closed intensive shrimp farming system practiced. This allowed high fry stocking in a wide range of densities (40 PL/m^2 to 200 PL/m^2) and consequently, increased shrimp production to nearly 600 000 tonnes during 2009-2010. However, the outbreak of Early Mortality Syndrome or Acute Hepatopancreatic Necrosis Disease (EMS/AHPND) in whiteleg shrimp, again reduced the production to 217 437 tonnes in 2014. Good aquaculture practices for marine shrimp farming were developed and disseminated for use by farmers as the principle source of guidance and a voluntary standard for sustainable intensive shrimp farming. The practices include pond preparation, fry stocking, feed and feeding, water quality, disease and health management, food safety management, and effluent and sediment management.

The shrimp industry of Thailand benefited from the establishment of closed intensive shrimp farming. The sufficient supply of raw material and progressive production of shrimp farming created an export income of over USD3 000 million annually, created jobs and ancillary industries. The key factors in the success are technology development, which provides tools/materials for shrimp farmers to improve efficiency in farm management such as hatchery technology, formulated feed and material supply, aeration and water exchange, low water exchange technology, specific pathogen free (SPF) animals, biosecurity and disinfection, genetic improvement, probiotics and automatic feeder development. The threat to the high potential of closed intensive shrimp farming from emerging diseases, especially the last outbreak of EMS/AHPND, comes from the accumulation of organic wastes. This outbreak resulted in significant losses and discouraged farmers from adopting the new technology and new farm management concepts of shrimp production. The balance between the economic growth of the shrimp farming sector and the quality and availability of critical inputs and technology needs to be well managed for future sustainability.

Introduction

Thailand possesses over 2 700 km of coastline and a tropical climate, optimum for farming marine finfish and shellfish species including shrimps (Szuster, 2006). Basic biophysical factors and the presence of appropriate aquaculture technologies are also critical in supporting the strong growth of shrimp farming in Thailand (Kongkeo, 1995). The first shrimp farming was probably introduced to coastal Thailand during the 1930s (Tookwinas, 1999) using traditional extensive techniques in large enclosed low-lying coastal paddy fields (30 ha or more). Yields of shrimp were usually low (approximately 200 kg/ha/yr) because of the dependence on natural tidal flow for wild seed and naturally occurring food organisms (Szuster, 2006).

Semi-intensive shrimp farming in Thailand started during the early 1970s but was replaced by intensive shrimp farming beginning in 1987. Black tiger shrimp was selected for mono-species culture because of the availability of hatchery-raised black tiger shrimp (*Penaeus monodon*) postlarvae and its ability to grow fast under semi-intensive conditions with a fry stocking density of about 5 PL/m^2 to 10 PL/m^2. Semi-intensive shrimp culture uses ponds smaller than traditional extensive farms (1 ha to 8 ha), but provides significantly higher yields of up to 1 000 kg/ha/yr (Szuster, 2006).

Since 1987, shrimp culture in Thailand has gradually developed into intensive shrimp farming of black tiger shrimp (Tookwinas, 1999) at a fry stocking density of 20 PL/m^2 to 40 Pl/m^2. During this period, the open system was used to maintain good pond water quality to accelerate good production of the shrimp. The yield obtained from this open system was about 4 000 to 10 000 kg/ha/yr (2 cycles/yr). This raised farm production from 23 566 tonnes to about 263 500 tonnes in 1994 (Figure 1).

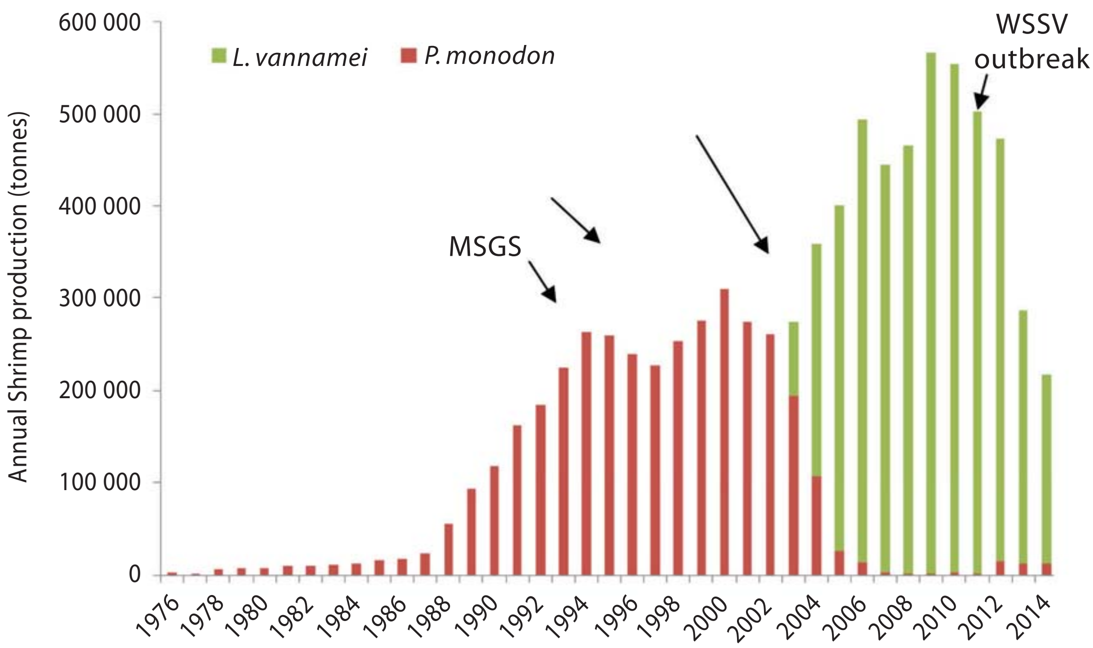

Figure 1 Annual shrimp production (tonnes) in Thailand from 1978 to 2014 indicating the year of major disease outbreak and the period of transition from *P. monodon* to *L. vannamei* culture

This rapid growth in shrimp farming also resulted in some notable negative impacts such as the outbreak of YHV (Yellow Head Virus) during 1992 and WSSV (White Spot Syndrome Virus) during 1994 (Booyaratpalin, 1999). The closed (semi-closed) intensive shrimp farming system and biosecurity measures at a fry stocking density of 40 PL/m^2 to 60 PL/m^2 were developed to replace the open system which increased the shrimp production to about 309 862 tonnes by the end of 2000. In 2002, the symptoms of Monodon Slow Growth Syndrome (MSGS) were reported throughout the shrimp farming areas in Thailand and the figures indicated that the annual production volume was reduced by approximately 36 percent (Flegel, 2008). This was the most significant shrimp disease outbreak in Thailand that stopped the growth of *P. monodon* culture in intensive farming. The intensive shrimp culture in Thailand underwent a great change during 2003-2004 with the introduction of whiteleg shrimp (*Litopenaeus vannamei*) to replace *P. monodon*.

Whiteleg shrimp made a good adaptation to the tropical climate and the closed intensive shrimp farming system practiced in Thailand. In addition, the success of the breeding programme to promote fast growth in whiteleg shrimp and the new super intensive farming technology were developed in Thailand during 2005 to 2008. This allowed a wide range of increased fry stocking densities of between 40 PL/m^2 to 200 PL/m^2 and the yields intensified to about 8 000 kg/ha/yr to 30 000 kg/ha/yr, which led to high shrimp production in Thailand of nearly 600 000 tonnes during 2009-2010 (Figure 1). However, the outbreak of Early Mortality Syndrome or Acute Hepatopancreatic Necrosis Disease (EMS/AHPND) caused by *Vibrio parahaemolyticus* (a toxin producing strain) as a new emerging disease was reported in China in 2009, in Viet Nam and Malaysia in 2010 and 2011, respectively (Eduardo and Mohan, 2012). The first report of EMS/AHPND in Thailand was during late August 2011 in the ponds located in the eastern province of Thailand (Chucherd, 2013). The EMS/AHPND has been the last emerging shrimp disease in Thailand that attacked the shrimp farms and led to serious decline of shrimp production to about 217 437 tonnes by the end of 2014 and the impact of the outbreak has not only reduced the production but the fear created is hindering recovery.

Marine shrimp has immense economic importance for Thailand. However, the rapid increase of shrimp farming and trade also ushered in concerns regarding the potential negative impacts of shrimp farming on the environment, communities and consumers and food safety. Thus, there is a fundamental need to establish standards to promote the sustainable development of intensive shrimp farming in terms of quality and safety of the production and with an acceptance at both domestic and international levels. This standard is called "Good Aquaculture Practices for Marine Shrimp Farm" (TAS 7401-2009). The establishment of this standard is based on information from the successful demonstration of Thai national voluntary standards on "Good Aquaculture Practice (GAP) in Marine Shrimp Farms" in 2005, and the "Code of Conduct for Responsible Marine Shrimp Aquaculture (CoC)" in 2003, as well as the "FAO Code of Conduct for Responsible Fisheries" in 1999 and the "CAC/RCP 52-2003, Rev 2-2005 Code of Practice for Fish and Fishery Products" in 2005. This "TAS 7401-2009" has highlighted the good aquaculture practices as a principle requirement for shrimp culture, especially in the management of intensive shrimp farming (National Bureau of Agricultural Commodity and Food Standards, 2010).

1. Good aquaculture practices

Good aquaculture practices were developed and disseminated for use as the principle guidance for sustainable intensive shrimp farming in Thailand. The good practice is aimed to prevent contamination and environmental deterioration, which can happen from routine farming activities. Shrimp health is also maintained by reducing water pollution, which is responsible for shrimp stress and disease susceptibility. The guidance for good aquaculture practices related to the above issues is summarized below (National Bureau of Agricultural Commodity and Food Standards, 2010).

1.1 Pond preparation

Pond vacating and/or appropriate preparation should be practiced prior to starting a new crop in order to remove the excess organic matters and nutrients that could degrade the water and sediment qualities when new shrimps are grown.

1.2 Fry stocking

Healthy fry should be obtained only from certified hatcheries. Stocking density should be appropriate in order to minimize stress and single species culture is preferred. The recommended stocking density is 60 PL/m^2 to 90 PL/m^2 for the shrimp post larvae (PL) 12 stage and for a four month culture period with expected yield size of 50 shrimp/kg to 60 shrimp/kg. If the target size is 40 shrimp/kg to 50 shrimp/kg, the appropriate stocking density is about 50 PL/m^2 to 60 PL/m^2. Farmers should increase the water exchange rate and aeration in accordance with the density.

1.3 Feed and feeding

In practice, farmers should feed at the rate of 1 to 2 kg/100 000 shrimp/day depending on stocking density of fry and the amount of natural feeds available in the pond. The increase of daily feeding is fixed at the rate of 0.5 to 1 kg /100 000 shrimp/day until the shrimp reaches the age of 15 to 20 days, when a feeding tray can be used for regular assessment of feed consumption. The adjustment of the feeding rate can be practiced at each feeding schedule according to the results of feeding tray examination. Substances prohibited by the law are not allowed to be used as ingredients. Farmers are recommended to regularly examine the quality of feed. Feed storage areas should be dry, clean and with a proper condition to maintain feed quality, temperature, and prevent access by disease-carriers such as rats, birds and other animals. The feed bag or sack should be held elevated over a platform for moisture prevention and good ventilation. Fresh feed is allowed only in case of absolute necessity and if used, proper management should be practiced to prevent water pollution.

1.4 Water quality

An aerator should be installed to maintain optimum environmental conditions for shrimp growth and located in a proper position to reduce soil leaching into the pond. For efficient shrimp farm management, water should be maintained at an appropriate depth for good oxygen management. Water quality should be maintained at the recommended levels as given in Table 1.

1.5 Disease and health management

Prevention of diseases is the most suitable approach to control and maintain shrimp in good health. Good health management can reduce stress and maintain normal growth and a high survival rate. Good health management also involves the examination of shrimp health, feed quality and feeding, water and sediment quality management. The recommendations on good shrimp health management are as follows:

- Regularly check the shrimp health and water quality. If any health problem is found, diagnosis and analysis should be done immediately.
- If any dead or diseased shrimp is found, diagnosis of symptoms should be done immediately. Efforts to improve water quality, reduce feed or increase aeration should be maade in order to reduce stress on the shrimp. If shrimp mortality is continuously observed, the harvest of the shrimp crop is recommended.

Table 1 Recommendation of suitable water quality for marine shrimp farming production

Parameters	Suitable level
Temperature	28°C to 32°C
Dissolved oxygen	≥5 mg/l
pH	7.0 to 8.3
Salinity	0.5 to 35 mg/g
Chloride	≥300 mg/kg
Sodium	≥200 mg/kg
Calcium hardness (as $CaCO_3$)	≥100 mg/kg
Magnesium hardness (as $CaCO_3$)	≥50 mg/kg
Total alkalinity (as $CaCO_3$)	≥100 mg/kg
Ammonia (NH_3)	≤0.4 mg/l
Nitrite (NO_2^-)	≤1 mg/l
Nitrate (NO_3^-)	≤60 mg/l
Total suspended solid	≥100 mg/l
Total coliform bacteria	≤1 000 MPN/100 ml
Faecal coliform bacteria	<70 cfu/100 ml

Source: National Bureau of Agricultural Commodity and Food Standards (2010)

- Strict preventive measures such as disinfection of farm equipment, assigning a responsible worker for such infected pond and stopping water exchange should be in place to control the disease transmission from pond to pond or from farm to farm.
- In case of an outbreak of aquatic animal disease, the competent authority, surrounding farmers, and members of the shrimp organization should be notified immediately. The diseases requiring immediate notification are White Spot Syndrome Virus (WSSV), Yellow Head Virus (YHV), Taura Syndrome Virus (TSV) and Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV).
- Materials and equipment such as seine and net should be used to screen out pest and disease carriers from the pond during the pond preparation, water preparation and culture of shrimp.

1.6 Food safety management

The use of veterinary drugs and chemicals should be regarded as the last resort in shrimp health management and disease control because veterinary drugs and some chemicals can have residual effects on shrimp and subsequently might be harmful to consumers. In fact, the improvement of the culture pond environment is the best way for better health and recovery from disease infection. Disease prevention and disease treatment are specifically dependent on the causes of a particular disease. The recommendations are as follows:

- Veterinary drugs registered with the competent authority should be applied only. The veterinary drugs on the banned list for aquaculture under the national regulation and on the banned list of the importing countries are not allowed. The application of veterinary drugs should be restricted according to the manufacturer's instructions for relevant drugs as well as the withdrawal period.
- The storage of veterinary drugs should be adhered to as per recommended directions. Veterinary drugs prescribed by a veterinarian should be separately kept from nonprescription drugs.

- Veterinary drugs should be used only after the disease is properly diagnosed under the supervision of a veterinarian or fishery biologist who is an expert in aquatic animal diseases. Expired veterinary drugs according to product label should not be used. The handling or disposal of expired veterinary drugs should be done in a responsible manner.
- Hazardous substances and probiotics for aquaculture registered with the competent authority and allowed under national regulations and regulations of the importing countries should be used in accordance with the recommended methods.

1.7 Effluent and sediment management

Effluents contain high levels of nutrients, micro-organisms, planktons, and other substances. Good farming practice aims to reduce the amount by improving the quality of the effluent and meeting the stipulated legal standards. Sediment and effluent management should be done properly to avoid adverse environmental impacts. The recommendations are as follows:

- Regularly maintain inlet and outlet canals and dike to reduce soil leaching and sedimentation.
- Use organic fertilizer from an organic agricultural farm to increase the natural feeds if necessary. This should be done with efficient feeding to minimize the excessive supply of feed.
- Effluent should be treated or subject to quality control before being discharged. The effluent parameters should meet standards as required by law as shown in Table 2.
- Precaution should be taken during effluent discharge to control the floating of suspended particles. Flow rate of the effluent discharge should be controlled.
- Effluent and sediment should not cause adverse environmental impacts.
- Effluent should not be discharged to fresh water canals and arable lands.
- Sediment discharge should not cause adverse environmental impacts. If possible these sediments should be reused.
- Sediments from culture ponds, outlet canals and reservoirs should be reused or discharged without causing adverse environmental impacts.
- Material or tools such as net or seine at the inlet and outlet water should be used to prevent shrimp from escaping.

Table 2 Notifications of the Ministry of Natural Resource and Environment Re: Specification of the standard controlling discharge of effluent from coastal aquaculture Pond (B.E. 2550)

	Parameter	Standard
1	pH	6.5 to 8.5
2	BOD	≤20 mg/l
3	Suspension solid	≤70 mg/l
4	NH_3-N	≤1.1 mgN/l
5	Total phosphorus	≤0.4 mgP/l
6	Total nitrogen	≤4.0 mgN/l
7	Hydrogen Sulfide	≤0.01 mg/l

Source: Pollution Control Department (2002)

1.8 Implementation of the standards

To maintain its international reputation as a producer of safe quality products, the Thai Agricultural Standard (TAS 7401-2009) on Good Aquaculture Practices for Marine Shrimp Farms in accordance with the FAO Guidelines on Aquaculture Certification has been used as a voluntary standard for shrimp farming (National Bureau of Agricultural Commodity and Food Standards, 2009).

The GAP (TAS 7401-2009) was implemented on a voluntary basis in accordance with the Ministerial Notification of Agriculture and Cooperatives on 29 September 2009 (National Bureau of Agricultural Commodity and Food Standards, 2009). The standards on animal health and welfare were selected to ensure the health and welfare of farmed aquatic animals by minimizing stress, reducing aquatic animal disease risks, and maintaining a healthy culture environment throughout all phases of the production cycle. The standards on food safety were selected to ensure food safety and conform to national and international standards and regulations, including those defined by FAO/WHO Codex Alimentarius. The standards on environmental integrity focus on ensuring that aquaculture practices are carried out in an environmentally responsible manner. The standards on socio-economic aspects were selected to ensure that the aquacultural activities are conducted in a socially responsible manner in accordance with national rules and regulations and also taking into consideration the International Labour Organization (ILO) convention on labour rights, not jeopardizing the livelihoods of aquaculture workers and local communities (Prompoj *et al.*, 2011).

1.9 Benefits to the shrimp industry in Thailand

The Thai Frozen Foods Association (TFFA) reported that during the past twenty years, frozen and processed shrimp were the most important export commodities among the fishery commodities of Thailand (Thai Frozen Foods Association, 2012b). This is because closed intensive shrimp farming in Thailand is well established in terms of technology development and transfer to farmers, which has resulted in a sufficient supply of raw material for the shrimp industry. The production of closed intensive shrimp farming created an export income of over USD3 000 million annually during 2010–2011 (Table 3). The large benefit of the Thai shrimp industry during this period was also contributed by the global reduction in shrimp production because of natural disasters and disease epidemics encountered in several shrimp producing countries that led to the higher price adjustment (Thai Frozen Foods Association, 2012a). Although there was a slight reduction in shrimp exports from Thailand in 2011, the value increased to over 100 000 million Baht. Almost all of this was from the value addition related to the variety of shrimp products made available. This was also responsible for significant job creation within the related industries.

Table 3 Overview on the status of the production in Thailand's shrimp industry during 2007–2011 (data collected from Department of Fisheries and Department of Foreign Trade)

Thai shrimp production (tonnes)	Year				
	2007	2008	2009	2010	2011
White shrimp	441 451	464 418	565 914	552 319	550 147
Tiger prawn	3 299	1 911	1 056	2 426	1 103
**Domestic consumption	44 475	45 000	55 000	55 000	55 000
Import (tonnes)	15 926	19 575	19 392	21 988	23 079
Value (million baht)	1 516	3 095	1 640	1 628	1 234
Export (tonnes)	354 432	358 619	398 658	427 723	326 441
Value (million baht)	81 404	84 149	93 372	101 069	90 819

Source: Thai Frozen Foods Association (2012a)

2. Lessons learned

The development of closed intensive shrimp farming has been one of the recent success stories in Thailand. The main keys to success are technology development, which provides tools/materials for shrimp farmers to improve their efficiency in terms of farm management, and overcoming the threat from emerging diseases. The details are summarized below based on farm observation data and the common practices of farmers.

2.1 Technological development

2.1.1 Hatchery technology

Closed intensive shrimp farming requires large quantity of fry that allows simultaneous stocking. Hatchery technology is essential for the production of good quality and healthy shrimp fry on a large commercial scale instead of collecting from the wild. This technology consists of water preparation, shrimp maturation, reproductive induction, spawn and eggs fertilization, larvae rearing, feeding with cultured marine microalgae and live artemia, and other hatchery management tasks until the post larvae (PL) stage within a period of three weeks. The demand for whiteleg shrimp fry for close intensive shrimp farming was about 65 000 million PL/yr to 78 000 million PL/yr prior to the outbreak of EMS/AHPND whereas during the outbreak, the demand reduced to 52 000 million PL/yr. The number of active shrimp hatcheries operating in Thailand, large, medium and small (backyard hatcheries), ranges from 1 000 to 2 000 hatcheries, depending on the demand for shrimp fry from the industry.

2.1.2 Formulated feed and material supply

With the high stocking densities typical of a closed intensive culture system, natural food organisms do not supply enough nutrition and the farmer must provide a nutritionally complete and balanced ration. Feeding efficiency is crucial, as high quality feeds are very expensive compared to the supplemental feeds used in semi-intensive culture. The shrimp industry of Thailand mostly uses formulated high quality feed (high protein) instead of using fresh feed or farm produced feed. The annual feed consumption is estimated to be about 900 000 tonnes (for the production of 600 000 tonnes and an average FCR about 1.5). Twenty-two feed producers are registered with the Department of Fisheries, Thailand. There are also about 50 to 100 companies that supply farm chemicals and materials for water disinfection, improvement and management of water quality and the culture environment. All of these feed factories and companies employ large numbers of staff, i.e. office personnel, factory technicians, biologists, sales extension personnel etc., which create a large number of jobs and job opportunities in Thailand.

2.1.3 Aeration and water exchange

Intensive shrimp farming demands good quality of water and pond sediment to promote good growth. The excess organic wastes and nutrients from shrimp feeding usually results in dense phytoplankton, high oxygen demand and large fluctuation of the daily oxygen level and pH to the sub-optimum range. Thus, aeration should be sufficient for all routine oxygen demands from shrimp, especially during molting. Moreover, it should be sufficient for the microbial and phytoplankton oxygen demand. The sufficient use of aeration can prevent the bloom-bush of phytoplankton, maintain a stable pH environment and promote shrimp feeding. Water exchange with new clean water from the reservoir is also important in order to reduce waste and increase dissolved oxygen. The amount of water exchange should be less than 5 percent to 10 percent, which is suitable for the intensive system. Too much water exchange could result in a phytoplankton drop in the pond because of sudden and frequent changes in the water condition.

2.1.4 Low water exchange

Low water exchange in shrimp culture is useful to enhance environmental sustainability through minimizing the discharge of pollutants and reducing the risk of contamination with diseases or the introduction of disease carriers or predators that can come through water from external sources. This is one of the most efficient ways to prevent disease outbreaks, especially from water exchange. The low water exchange must be complemented with sufficient aeration to compensate for the low levels of oxygen in especially warm and highly saline water.

2.1.5 Specific pathogen free (SPF)

For farming of whiteleg shrimp, the breeding and maturation of broodstock are carried out in a specific pathogen free facility. The status of SPF should mean that the shrimp have passed through a rigorous quarantine and disease screening process that determined them to be free from specified pathogens, for at least a continuous period of two years and supply healthy nauplii/shrimp fry for farming purposes. In addition, the SPF status could support the domestication programme and adapt the shrimp broodstock to the culture environment. This can enhance the shrimp condition and feeding behavior as well as ensure that it is adapted to the environment of the closed/low water exchange system.

2.1.6 Biosecurity and disinfection

Biosecurity is often defined as practice that reduces the number of pathogens that enter a facility. Biosecurity in shrimp farming is the concept of protecting cultured shrimp from contamination by diseases and of preventing the transboundary spread of diseases. This has become increasingly important with the intensification of shrimp farming and the other aquaculture production systems. The efficiency of biosecurity depends on the scale of the farm operation. Uses of quarantine broodstock, specific pathogen-free (SPF) certified nauplii, and disinfected water and hatchery materials/tools are recommended as good biosecurity practices in a hatchery. Physical measures such as the wearing of footwear and clothing are used to prevent the intrusion of disease-carrying vectors by humans. The exclusion of disease vectors, especially vectors of shrimp viral disease during pond preparation, must be ensured on the farms. Chlorine and iodine are often used to treat incoming water and materials before they enter the facility or to treat other potential vectors and carriers. The use of shrimp fry from the biosecurity hatchery is recommended to reduce the disease intrusion through transportation. In addition, the practices of providing better environmental and biological conditions to promote shrimp health can support the achievement of biosecurity operations at farm level.

2.1.7 Genetic improvement programme

The planned breeding programmes of whiteleg shrimp have proven to increase profitability through genetic improvement for growth and disease resistance in shrimp. The genetic improvement programme in whiteleg shrimp is commercially developed in Thailand under closed intensive farm conditions using a family selection breeding programme. A final significant improvement is related to growth performance: results revealed that the growth rate observed in many areas increased from an average of about 60 count/kg within 100 days of culture (0.17 g/d) to about 60 count/kg within 70 to 80 days (0.21 g/d to 0.24 g/d). The selective breeding programme that promotes disease resistance to WSSV and *Vibrio* spp in the SPF breeding programme is attracting shrimp farmers to engage in closed intensive shrimp farming because of the availability of shrimp PL that are less susceptible to specific pathogens.

2.1.8 Probiotics

Water quality includes all physico-chemical and microbiological characteristics of shrimp culture pond water. Nutrient and organic wastes produced by intensive shrimp farming consist of solid matter (mainly uneaten feed, faeces and phytoplankton) and dissolved metabolic wastes (mainly, urea, NH_3 and CO_2) that are sources of nutrients promoting the growth of phytoplankton and bacteria consuming oxygen and pose a risk of disease outbreak when shrimps are stressed or made unhealthy by the wastes. Probiotics is an effective biological measure, containing a mix of bacterial species (mainly *Bacillus* and *Lactobacillus*) to establish beneficial microbial communities under culture conditions. The application of probiotics in closed intensive shrimp farming aims to accelerate the decomposition of the organic wastes in the pond reducing the harmful organic waste that accumulates in the pond area. The application of proper probiotics is able to enhance microbial and phytoplankton populations and thus result in a healthy ecosystem in the pond as well as a reduction of toxic nitrogen wastes through the re-mineralization by probiotic populations. The use of probiotics directly regulates water quality especially in terms of a stable pH within 7.5 to 8.0, which is suitable for the healthy growth of shrimps.

2.1.9 Automatic feeder

An automatic feeder is often used and is popular with the closed intensive shrimp farmers, especially those farmers who have medium-scale and large-scale shrimp farms. A significant use has been extensively observed in Thailand since 2009. The efficient use of an automatic feeder is recommended at the rate of 300 000 shrimp/unit to 600 000 shrimp/unit depending on the pond size and shape. The feeding should be monitored according to the amount of residual feed remaining in the feeder without manually adding to the trays. If there is leftover feed on the trays, the feeding programme of the automatic feeder machine should be adjusted to reduce the feeding dispersal rate.

2.2 Emergence of disease

The sustainability of closed intensive shrimp farming is often queried when shrimp production shows a significant decline. Disease is one of the main threats causing production failure and rising production costs of shrimp, which reduce the sustainability of the shrimp farms and the industry. There are two examples (presented below) that can be used as lessons learned from closed intensive shrimp farming in Thailand.

2.2.1 Monodon Slow Growth Syndrome (MSGS)

During 2002 to 2004, there was a significant outbreak of MSGS in Thailand's shrimp industry, which adversely impacted the *P. monodon* farming in Thailand. The main characteristic of the disease was abnormal retarded growth leading to a wide variation in size. Fortunately, there was no mass mortality. During the period of MSGS outbreak, there was a consistant decline in *P. monodon* production from 260 573 tonnes in 2002 to 106 884 tonnes in 2004 and about 1 056 tonnes in 2009 (Table 4). MSGS was first observed in cultured *P. monodon* in Thailand and because of the lack of affinity to any known viral pathogens, the causative agent was designated as Monodon Slow Growth Agent (MSGA). Later investigations revealed the presence of a virus called Laem-Singh Virus (LSNV).

2.2.2 Early Mortality Syndrome/Acute Hepatopancreatic Necrosis Disease (EMS/AHPND)

The recent outbreak of EMS/AHPND has threatened the success of intensive whiteleg shrimp farming in Thailand and other shrimp producing countries, including China, Viet Nam and Malaysia that have adopted intensive shrimp farm management techniques. The outbreak caused by *Vibrio* *parahaemolyticus* (a toxin producing strain) is associated with organic matter and accumulated wastes from shrimp feeding. The excess organic matter promotes the pathogenic bacteria stain to the level of infection and produces toxins that destroy the hepatopancreas of the shrimp and cause mass mortality of the shrimp at the early stage of harvest. Data shown in Table 5 reveal the large impact of this outbreak on the shrimp culture production over three years of continuous outbreak (2012–2014) in comparison with the production in 2011 of about 529 016 tonnes. The Department of Fisheries estimated that this loss has created a feeling of fear among farmers and is discouraging them from continuing with shrimp farming. The slow growth of the shrimp and the high mortality were the other factors contributing to the loss of shrimp production.

Table 4 Decline of *P. monodon* production during the outbreak of Monodon Slow Growth Syndrome (MSGS) (2002–2004) and the substitution with whiteleg shrimp (*L. vannamei*) in Thailand starting from 2004

Year	Annual production (tonnes)		
	P. monodon	*L. vannamei*	Total
2002	260 573.00	0.00	260 573.00
2003	194 909.00	79 258.00	274 167.00
2004	106 884.00	251 697.00	358 581.00
2005	26 055.00	374 487.00	400 542.00
2006	13 986.00	480 061.00	494 047.00
2007	3 300.56	441 450.75	444 751.31
2008	1 909.39	464 420.30	466 329.69
2009	1 056.14	565 920.14	566 976.28

Source: Anon, 2013

Table 5 The impact of EMS/AHPND outbreak on shrimp production in Thailand and potential loss of shrimp production in comparison with the production in 2011

Year	Annual production (tonnes)			Potential loss of shrimp production during the outbreak of EMS/AHPND in comparison with production in 2011
	P. monodon	*L. vannamei*	Total	
2011	1 468.7	500 719.5	502 188.1	–
2012	15 218.9	458 011.9	473 230.8	28 957.3
2013	12 124.3	274 754.6	286 878.9	215 309.2
2014	13 052.6	204 385.4	217 438.0	284 750.2
Total potential loss in shrimp production				529 016.7

Source: Anon, 2014.

3. The way forward

Sustainability is the ultimate goal of all development programmes. Shrimp farming in Thailand is one of the good examples of sustainable development. The development of shrimp farming in Thailand started with the extensive farming system (density depending on wild seeds) and later changed to the closed intensive system with a wide range of stocking densities (40 PL/m^2 to 200 PL/m^2). Shrimp production in Thailand increased after this new technology was developed and widely used. Disease outbreaks were often noted to occur when the demand for inputs for the shrimp sector was higher than the supplies such as quality broodstock, fry, feed pellets and farm equipment. This can simply be described as an imbalance in the shrimp sector. The balance between the economic growth in the shrimp sector and the quality supply of materials (shrimp, feed, other materials) and technology used in shrimp farming needs to achieve equilibrium if the industry is to be managed to ensure its sustainability. The role of government, academia and research institutes, and the private sector in the shrimp industry should be integrated and strategically managed to achieve the ultimate goal of sustainable intensive shrimp farming. Some suggestions and ways forward are as follows:

- Regular risk analysis of closed intensive shrimp farming to obtain up-to-date risk information and to plan for efficient management according to existing problems at national and regional levels must be undertaken.
- The negative impacts and risks should be made known to farmers and relevant stakeholders in order to warn and minimize and mitigate the impacts and manage the risks.
- New technologies and improvements for closed intensive shrimp farming should be regularly developed by academia and research institutes for serving future needs.
- Strategic management to prevent the imbalance in demand and supply of critical inputs in the shrimp sector should be addressed at national level for the sustainability of closed intensive shrimp farming.

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Annex I: Regional workshop on documentation and dissemination of successful practices of sustainable intensification of aquaculture in the Asia-Pacific region

16–18 June 2015, Bangkok, Thailand

Workshop Prospectus

Introduction

Intensification of aquaculture has been a driver to the rapid aquaculture growth (nearly 10 percent annually) in the Asia in the past two decades, which has significantly contributed to food security and nutrition of the people, rural livelihood and overall economy in the region. The region has constantly contributed over 90 percent of the world aquaculture production for decades. Aquaculture currently supplies 50 percent food fish for the world. In Asia, aquaculture supplies over 60 percent food fish, comprising over 20 percent of total protein intake by the Asian population. Needless to say, that there have been repercussions of intensification, such as negative impacts on environment, issue with biosecurity and food safety and problems related to socio-economics, which have attracted considerable public concern regarding the long-term sustainability of the sector.

Being the most populous region of the world with heavy demands on natural resources, Asian aquaculture will face great challenges to maintain its growth, to meet the increasing demand for fish inside and outside the region over the coming decades. It is estimated that fish consumption in Asia and the Pacific will increase by 30 percent by 2030. It implies the aquaculture production will need to increase by 50 percent by 2030 from the present level due to the stagnant capture fish production. Intensification of aquaculture has been an ongoing process in the region, which aims to increase the productivity and economic efficiency of aquaculture production through intensified use of inputs (materials, energy and investment) and resources (water, feed ingredients), application of new technologies and more efficient management practices.

Working with limited natural resource and various challenges, the most effective approach to meet the increasing demand for fish is to promote **Sustainable Intensification of Aquaculture** (**SIA**), which means "to produce more with less"– to increase the productivity and efficiency in aquaculture production while reducing the consumption of resources and negative environmental and social impacts through improved governance, management practices and adoption of innovative technologies. In order to support sustainable growth of aquaculture for contributing to increased fish supply for food and nutrition, increased livelihood opportunities and overall economic growth in the region, FAO is currently implementing a regional initiative on sustainable intensification of aquaculture for blue growth in Asia-Pacific. A great number of aquaculture production and management practices have been innovatively developed and applied by aquaculture practitioners and managers to improve the sustainability of intensive aquaculture in the region. Therefore, documentation and dissemination of existing successful production and management practices for sustainability of aquaculture intensification has be identified as an important approach to implement the regional initiative.

Rationale

The Network of Aquaculture Centres in Asia-Pacific (NACA) and Food and Agricultural Organization (FAO) are pursuing to work jointly in documenting and disseminating existing successful production and management practices for sustainability of aquaculture intensification in the region. This documentation and dissemination of successful production and management practices of SIA is seen as an important approach to promote SIA for sustainable economic growth of the region.

Objective

This initiative envisages a focused drive to identify, evaluate and document the practices/cases that meet the criteria of *sustainable* intensification of aquaculture, given proven benefits to aquaculture, farmers or communities and at the same time have potential for replicating in other parts of the region.

This exercise will bring out in documented form and also provide an avenue of presenting these success stories to other potential users and platform for cross-learning to support dissemination of successful cases in other regions of Asia-Pacific.

Expected outputs:

The workshop is to produce the following outputs:

- Significantly increased awareness to existing successful practices of sustainable intensification in the region;
- Recommendations and guidance for author experts to modify and finalize their documentation on successful practices of sustainable intensification in the respective countries;
- A draft regional synthesis report on successful practices of sustainable intensification in Asia-Pacific
- Strategy for dissemination and scaling up the documented successful practices of sustainable intensification in Asia-Pacific; and
- Draft version of FAO-NACA joint publication on successful practices of sustainable intensification in Asia-Pacific.

Participants

The workshop will be participated by the experts identified for the selected SIA cases from the respective countries and experts from other countries in Asia and the Pacific, which are not represented in the documentation process.

Workshop modality

The author experts for documenting the selected cases of successful practice of sustainable intensification of aquaculture will present the documented successful practice of SIA. Each presentation will be followed by plenary discussions on how to modify the documentation for comprehensiveness.

The participants including experts will spread into heterogeneous groups from different countries and will make focussed discussions on utility of the SIA cases, their potential and perspective regions of adaptation, likely benefits and identify gaps which need to be filled to achieve the upscaling of dissemination and strategies required. The groups will reshuffle again for discussions, so that all participants have chance to give inputs in this dissemination process. The outputs of group discussions will be presented during the plenary session.

Attempt will be made to produce a regional synthesis report on available and needed good practices in effectively addressing issues related to intensification of aquaculture in different dimensions.

Time and venue

Bangkok – Thailand, 16-18 June 2015. Venue: Centara Grand at Central Plaza Ladprao, http://www.centarahotelsresorts.com/centaragrand/cglb/index.asp; 1695 Phaholyothin Road, Chatuchak, Bangkok 10900, Tel. No. +66 2 541 1234

Post-workhsop Follow up

- The author experts will finalize the documentation of successful practices of SIA following the recommendation of the workshop
- NACA and FAO will finalize the synthesis report on these SIA practices
- A publication including all the documentation of all selected successful practices of SIA and synthesis report will be produced jointly by NACA and FAO and distributed to aquaculture planning and management authorities of countries in the region, relevant regional and international organizations and the workshop participants.

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Workshop Program

16–18 June, 2015

Hotel Centara Grand Ladprao, Bangkok, Thailand

Day 1, June 16, 2015		
Time	**Agenda**	**Remark**
08.30 –09.00	**Registration of Participants**	
Opening session		
09.00 –09.30	Welcoming remark by Dr Cherdsak Virapat, NACA DG Opening Remark by ADG/RR FAORAP	Chaired by Kuldeep K. Lal, NACA
09.30–09.45	Participants' introduction	All participants
09.45–10.15	Introduction to workshop objectives, process, expected outputs	FAO Officers and NACA
10.15–10.45	Group photo & coffee break	
Expert presentation session I: Improved supply of quality aquaculture inputs		
10.45–12.45	Development of improved common carp strain and its dissemination in China	**Zaijie Dong** China (FFRC)
	Development and dissemination of Genetically improved rohu (*Labeo rohita*) –"Jayanti" (India, Central Institute of freshwater Aquaculture)	**Kanta Das Mahapatra** India (CIFA)
	Development and dissemination of SPF Shrimp seed (*P. monodon*) in Thailand	**Boonsirm Withyachumnarnkul** Thailand (CENTEX)
12.45–14.00	Lunch break	
14.00–15.20	Successful development and dissemination of the mass grouper seed production technology in Indonesia	**Ketut Sugama** Indonesia (AMFR)
	Development and dissemination of low cost farm made formulated feed for improved production efficiency in polyculture	**Tapas Ghoshal** India (CIBA)
15.20–15.40	Coffee break	
Expert presentation session II: Improved socio-economic benefit of aquaculture		
15.40–17.40	Increase resilience and empowerment of small aqua farmers through cooperatives	**Yuan Xinhua** China (FFRC)
	Development of bivalve farming as source of income generation for women self-help groups in coastal India	**K.S. Mohamed** India (CMFRI)
	Integrated rural livelihood development through trout farming and related business in hilling areas (Nepal)	**Narayan Giri** Nepal (DOF)
18.00	Reception dinner	

Day 2, June 17, 2015		
Expert presentation session III: Improved planning and management of aquaculture		
08.30–10.30	A Science-based management Approach for Sustainable marine cage culture	**Joseph H.W. Lee** Hong Kong, SAR of China
	Integrated Multi-trophic aquaculture of fish, bivalves and seaweeds in Sanggou Bay	**Jihong Zhang** China (YFRC)
	Sustainable milkfish production in marine cages in the Philippines through strong government support and effective public-private partnerships	**Felix G. Ayson** Philippines (SEAFDEC)
10.30–10.50	Coffee break	
10.50–11.30	Development and dissemination of closed (semi-closed) intensive shrimp farming system (Thailand)	**Putth Songsangjinda** Thailand (DOF)
11.30–12.45	Assessment exercise	All participants
12.45–14.00	Lunch break	
Session IV: Development strategy for dissemination and scaling up good practices of SIA in the region		
14.00–15.30	Group Discussion session I	All participants
15.30–16.00	Group Discussion session II	
16.00–17.30	Presentation of group discussion	All participants
Day 3, June 18		
Session V: Presentation and discussion on draft regional synthesis report		
08.30–10.30	Presentation and discussion on draft regional synthesis report	All participants
10.30–10.50	Coffee break	
10.50–11.40	Plenary discussion on way forward	All participants
11.40–12.00	Closing session Feedback of representative of workshop participants Remark by NACA and FAO	
12.00–13.30	Lunch break	
Departure of participants		

Annex II: List of workshop participants

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Annex III: Assessment matrix for sustainable intensification of aquaculture

Practice	Environmental sustainability				Social acceptability					Production efficiency			Good governance		Overall
	Effluent discharge	Sustainable use of water & space	Biosecurity	Aquatic biodiversity	Gender equity[1]	Small holders benefit[2]	Social harmony (conflict)	Job opportunity	Food safety and quality	Output per unit water body	Economic return to investment	Efficiency in feed use	Regulation	Planning	
Development of improved common carp strain and its dissemination in China															
Development and dissemination of Genetically improved rohu (*Labeo rohita*) – "Jayanti" (India, Central Institute of freshwater Aquaculture)															
Development and dissemination of SPF Shrimp seed (*P. monodon*) in Thailand															
Successful development and dissemination of the mass grouper seed production technology in Indonesia															
Development and dissemination of low cost farm made formulated feed for improved production efficiency in polyculture.															
Increase resilience and empowerment of small aqua farmers through cooperatives															
Development of bivalve farming as source of income generation for women self-help groups in coastal India															
Integrated rural livelihood development through trout farming and related business in hilling areas (Nepal)															
A Science-based management Approach for Sustainable marine cage culture															
Integrated Multi-trophic aquaculture of fish, bivalves and seaweeds in Sanggou Bay															
Sustainable milkfish production in marine cages in the Philippines through strong government support and effective public-private partnerships															
Development and dissemination of closed (semi-closed) intensive shrimp farming system in Thailand															
Score system: assess the performance/ improvement of each practice against each indicator. Score 1 (lowest) to 4 (highest)															

[1] Equal participation and benefit of women

[2] How small farmer benefited from the production (benefit sharing along the value chain)

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