Food and Agriculture Organization of the United Nations

Sustainable intensification of aquaculture in the Asia-Pacific region

Documentation of successful practices

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REGIONAL OFFICE FOR ASIA AND THE PACIFIC
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Bangkok, 2016

Recommended citation

FAO. 2016. Sustainable intensification of aquaculture in the Asia-Pacific region. Documentation of successful practices. Miao, W. and Lal, K.K. (Ed.), Bangkok, Thailand.

Cover photo
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ISBN 978-92-5-109065-7

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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
Assistant Director-General and Regional Representative
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.

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

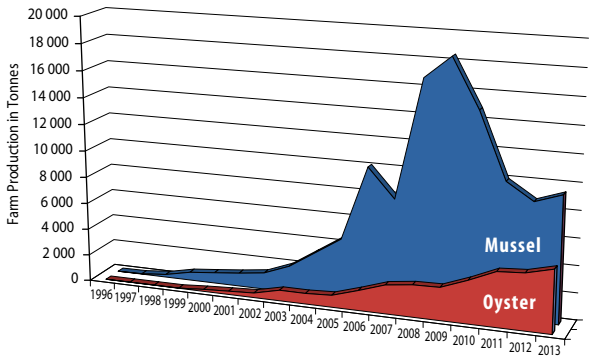
The successful transfer of technology for mussel and oyster farming in Kerala State resulted in a new model by which small-scale fishers, particularly women, could adopt an unconventional farming practice. After the sites were identified, the team scientists put up demonstration farms in close association 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)

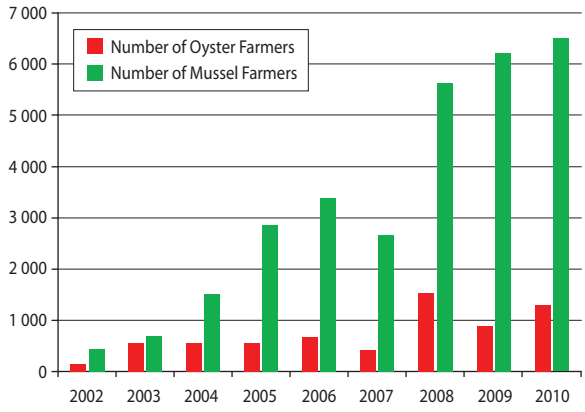


Figure 1b Growth in bivalve farming: number of farmers

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 18 to 25 extra women 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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