Supporting farmer innovations, recognizing indigenous knowledge and disseminating success stories

Expert Panel Review 6.4

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Abstract

The term "innovative farmers" refers to those who have tried or are trying out new and often value-adding practices, using their own knowledge and wisdom or through appropriation of outsiders' knowledge. It has been recognized that farmers' innovations are crucial in order to achieve cumulative growth, both economically and socially. In most cases, farmers' innovations are encouraged by the need to maintain economically viable production; in other cases, social needs such as food security are also drivers for innovation to increase income. Environmental sustainability, such as preservation or restoration of local species, has also been a driver of innovations in some regions. However, several social, political, economic and environmental factors have hampered farmers' innovation; these include lack of information on aquaculture, inadequate science and technology policies and lack of governmental support. At the commercial level, fish farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology. In terms of organization, innovation is a process that requires science to support technology development that is applicable to production.

Crucial factors needed to promote, encourage and support farmers' innovative processes are presented and discussed in this review, including changes in science and technology laws to promote knowledge-based adaptations, specific policies to encourage investment in innovation, educational policies focussed on developing specific profiles to manage technology-based aquaculture, appropriate personnel training and extension services, and policies that contribute to the development of aquaculture directed to specific social and cultural groups. Proper design interventions and policies can help to bring a much needed empathetic understanding and holistic vision in order to connect and integrate the various innovative efforts towards a positive outcome. These could provide adequate guidelines for developing countries in order to become transformed into innovation-driven economies.

The concepts of farmers' innovations are assessed from a broad spectrum of geographical areas and farming systems, and how these innovations have contributed and can contribute to food security, poverty alleviation and

sustainability is described. Successful interactions between science, technology and production which have contributed to innovation in both small-scale and commercial aquaculture are examined.

Equally important is the recognition of indigenous aquaculture practices all over the world; there are numerous examples that illustrate the good use of traditional knowledge in developing cost-effective and sustainable strategies to enhance poverty alleviation and income generation, in both developing and developed countries. We evaluate how indigenous knowledge principles can be used to promote environmentally friendly aquaculture practices.

Traditional knowledge is an important part of the lives of the poor: it is the basis for decision-making of communities in food security, health, education and natural resource management. We thus focus on how this knowledge has been adapted, applied and disseminated.

The case studies presented are expected to provide pathways to build effective partnerships between farmers, researchers and policy-makers; some of the major traditional knowledge has been subjected to scientific validation, and attempts have been made to improve them through the application of science-based approaches. However, there is a paucity of information on the vast amount of traditional knowledge that is prevalent in different societies and cultures all over the world.

Furthermore, we assess several strategies used for the dissemination of success stories, including both traditional and emerging approaches which have been effectively applied within the aquaculture sector development. Studies clearly reflect that wherever farmers have had access to adequate foundation knowledge on the science of a technology, they have been able to constantly improve the production systems, assuring sustainability and adaptation to local conditions. Examples that demonstrate how successful technologies and practices have been disseminated through different approaches are presented. For instance, the establishment of farmer field schools, cluster approaches and self-help groups in many locations of the world, as a way to transfer appropriate aquaculture technology is discussed and assessed. Moreover, dissemination methodologies followed by some of the most relevant regional aquaculture networks are also presented.

Lastly, we examine the extent that indigenous knowledge, farmers' innovations and innovative dissemination strategies have contributed to the rapid growth of the aquaculture sector in different parts of the world, and how these practices could be adequately documented and disseminated in the future. Further, we assess the need to promote effective partnerships between farmers and the scientific community; while the conventional dissemination strategies would help to spread the technology in a given location, newer institutional approaches and electronic systems can be used to cross geographical boundaries.

KEY WORDS: *Aquaculture, Indigenous knowledge, Information dissemination, Innovation, Success stories.*

Introduction

Aquaculture remained as the fastest-growing food production sector in the last decade, and without any doubt, the Bangkok Declaration, endorsed in 2000, has provided during the past decade, and will provide during the forthcoming years, the necessary guidelines to stimulate and promote the development of a sustainable and environmentally friendly aquaculture sector globally. The present report aims at assessing how indigenous knowledge and fish farmers' innovations have also contributed to global aquaculture development, and what types of strategy can be designed to safeguard and promote traditional and indigenous techniques wherever they exist. We also analyze and suggest appropriate mechanisms to build greater linkages between farmer innovators and the scientific community, in order to hasten the process of sustainable aquaculture development. Lastly, we identify and assess successful dissemination strategies that have contributed to the rapid development of aquaculture in the past decade and in various parts of the world, and suggest efficient and feasible ways of disseminating information to reach relevant stakeholders at all levels of the production chain.

Regarding fish farmer innovations and their linkage with small-scale aquaculture, we note that Asia has been the center of aquaculture production for decades, and currently, more than 90 percent of the total aquaculture production (in quantity) comes from Asian countries, China being the biggest producer in the world (FAO 2010). What is most interesting regarding these data is that more than 70 percent of the total aquaculture production comes from small-scale farmers producing in semi-intensive or semi-extensive farming systems, and who are also the major contributors of small-scale innovations and adaptations of aquaculture technologies developed in more developed regions of the world to suit their own local conditions. In many countries of the world where the required natural resources for aquaculture development are available but access to modern technologies is limited, thanks to the innovative potentials of farmers and through adaptation processes, farmers' innovations have been evolved and adapted to increase aquaculture production during the past decade (Edwards, 2009d, Nandeesha, 2007).

Examples will highlight the innovative potential of farmers, as well as the role of productive partnerships between farmers and scientists. Combined efforts between farmers and scientists have contributed to the rapid development of aquaculture in countries where resources were available and market demand for aquaculture products was present (De Silva and Davy, 2010). Furthermore, these fruitful farmer-scientist partnerships have shown that relevant technical constraints can be efficiently solved by involving farmers in the development process, since they have the field experience and the environmental wisdom that is needed. On the other hand, the implementation of adequate policies designed to stimulate and promote farmers' innovations has demonstrated the real benefit of involving a broad range of stakeholders in the expansion of the sector. As an example, India founded the National Innovation Foundation in order to promote grass-roots level innovations, having achieved amazing results that are discussed further in this paper (Nandeesha, 2007).

Lastly, there are several successful examples of technology transfer and dissemination strategies that have had major impact on aquaculture development in the past decade. Modern information and communications technologies (ICTs) have been and will be incredible dissemination strategies with minimal cost: electronic communication systems are nowadays helping to reach the masses with minimum efforts.

Bangkok Declaration: commitments and progress made

In the Bangkok Declaration, although there is no explicit statement on the three main components addressed by this review, namely: indigenous knowledge, farmer innovations and dissemination of aquaculture technology and information, the spirit behind these concepts can be traced in some of the statements made under different categories in the Bangkok declaration. For example, the statements made under Key Element 3.2 *Investing in research and development* clearly indicate that "stakeholder participation in research identification and implementation" should be considered as a key factor to accelerate finding solutions to problems. Similarly, under Key Element 3.3 *Improving information flow and communication*, there is an explicit statement on "making effective use of new technologies to improve information flows and management policies and practices within aquaculture". Substantial progress has been made regarding this specific topic during the past decade: technology transfer strategies and dissemination approaches have evolved amazingly during these last ten years, and illuminating and didactic examples of dissemination strategies will be described and analyzed.

In the sections presented below, we describe the progress accomplished, the challenges encountered and the suggested way forward to address the main gaps, limitations and constraints. In addition, evidence to provide special emphasis on safeguarding traditional knowledge for the benefit of humanity is also presented. Regarding farmer innovations, a broad range of illuminating case studies from all regions of the world and all types of production systems is analyzed and discussed, as well as the main limiting and promoting factors for innovation. The past decade has best witnessed the impact of information and communications technology (ICT) in all walks of life, and similar impact is witnessed in aquaculture. Opportunities to further scale up these positive developments to sustain and increase aquaculture production in the coming decade are detailed.

Recognizing indigenous knowledge

Concepts and background

This section presents examples and case studies which illustrate the amazing scope of indigenous and traditional wisdom existing in relation to aquatic production systems which are providing food and income to several thousands of families dependent on them.

The term " indigenous or traditional knowledge" is defined as "the knowledge stored in people's memories and activities, and expressed in the form of stories, songs, proverbs, dances, myths, folklore, cultural values, beliefs, rituals, community laws, local language and taxonomy, agricultural practices, equipment materials, plant species and animal breeds" (Grenier, 1998). Indigenous information systems are cumulative, dynamic, continually influenced by internal creativity and experimentation, as well as by contact with external systems (Flavier, De Jesus and Mavfarro, 1995). In many rural areas, the traditionally associated technical knowledge of fish farmers has been followed for generations to overcome different situational constraints (Gupta, 1990,). Farmers' traditional adaptations and innovations have little or no cost; they are readily available, socially acceptable, economically feasible and sustainable; they involve minimum risk to rural farmers and producers, and they are widely believed to conserve resources (Goswami, Mondal and Dana, 2006). The use of farmers' innovation, skills and wisdom promotes active community involvement because people depend more on each other; farmers' innovations encourage transparency and accountability (Ratnakar and Reddy, 1991). Indigenous knowledge contributes to the increased efficiency, effectiveness and sustainability of the development process (Rao, 2006). Regarding aquaculture, indigenous traditional knowledge of farmers all over the world has resulted in the development of sustainable and environmentally friendly aquaculture practices; some of the most relevant ones are presented in the following sections.

As will be described in the next sections, most of the indigenous and traditional practices are based on integrated approaches, where agriculture and/or livestock production are being integrated with fish farming as a way to increase natural resources efficiency and diversify income-generating activities. For instance, with regard to indigenous and traditional aquaculture strategies, rice-fish culture is considered among the most basic and may be the most ancient type of traditional integrated fish farming system in the world. Recent archaeological evidence has indicated the possible co-evolution of agriculture and integrated aquaculture systems since more than 8 000 years ago in China, where the earliest evidence of integrated fish-rice culture dates from 1775–1780 BP (Edwards, 2004). In India, where traditional aquaculture was mainly practiced along the coastline by fisheries communities, the most ancient traditional fish farming systems include the bheri system in West Bengal, the gheri system in Orissa, the pokkali system in Kerala, and the khar lands or gazani (coastal khar lands) in Karnataka; all of these will be analyzed in detail in the sections which follow. It should be noted that most of these traditional Indian systems are also integrated agriculture-aquaculture strategies that integrate fish production with rice or other crop cultivation (Jhingran, 1991; Sonak, Kazi and Abraham, 2005).

Integrated agrolivestock-fish production

Edwards, Pullin, and Gartner (1988) defined integrated aquaculture as "the concurrent or sequential linkage between two or more farm activities, of which at least one is aquaculture". Multitrophic aquaculture approaches and integrated fish farming systems such as crop-livestock-fish culture integration were developed by Chinese farmers thousands of years ago (FAO/ICLARM/IIRR, 2001), and they are still playing a major role as nutrient-recycling strategies in many developing countries of the world. In China itself, farmers are slowly moving from integration and polyculture systems towards more intensive monoculture strategies (Edwards 2009d); however, a considerable number of fish farmers still actively practice integrated farming in Asia and other regions of the world. At present, the integration of fish and agrolivestock production is becoming more relevant than ever in developed countries as an alternative to intensive and highly unsustainable farming strategies. Integrated farming is a green approach, an environmentally friendly strategy and a sustainable practice (Little and Edwards 2003; Edwards, 2006a,b). In Asia, fish culture in semi-intensive systems mainly depends on fertilizer nutrients. Moreover, with increasing need for multipurpose use of water resources, community waterbodies used for watering livestock are increasingly stocked with fish seed and their management intensified. Several studies of small-holder aquaculture in Bangladesh, India, Thailand and Viet Nam indicate that livestock wastes are the most commonly used inputs as organic fertilizers or supplemental feeding inputs (Edwards, 2008a,b, 2009a,b,c,d, 2010a,b,c,d). Fish yields may not be optimized for a variety of reasons, but livestock wastes purposely used in ponds or draining into them support the production of most cultured fish in Asia (Little and Edwards, 2003). The main linkages between livestock and fish production involve the direct use of livestock wastes, as well as the recycling of manure-based nutrients which function as fertilizers to stimulate the natural food web. The recycling of animal wastes in fish ponds as a major feeding source is important to small and medium-scale aquaculture practices all over the globe, in order to reduce expenditure on costly feeds and fertilizers, which could be more than 50 percent of the total input cost of a productive system. However, indiscriminate use of these manures in fishponds, instead of improving pond productivity, may lead to uncontrolled eutrophication, hypoxia and pollution (Edwards, 2008b). Integrated biosystems can be relatively sustainable and resilient, and have the potential to create a big positive impact on local economies (; Nandeesha, 2007; Edwards, 2009d). Although some infectious diseases (zoonoses and non-zoonoses) such as the swine flu and bird flu pandemics have created several animal and human health concerns regarding the possible biosecurity approaches to integration, the systems continue to provide a good opportunity to recycle animal and vegetable wastes as a key resource for poor farmers; integration at the family level continues to flourish in Asian and African aquaculture.

Integrated rice fish culture

Rice-fish culture is another traditional integrated food production system focused on integrated fish farming, which has, as well, a quite long history (Halwart 1998; Halwart and Gupta 2004). It has been considered the oldest type of "co-evolution" of agriculture and aquaculture production, with more than 8 000 years of history in China (Edwards, 2004). Modern rice-fish culture systems supported by well-constructed infrastructures, fish ponds and trenches, improved supplementary feeding practices and intensive management approaches are an outcome of farmers' self-learning through generations.

The rice-fish culture system as a source of food appears to be the oldest form of integration practiced by mankind. Cultivating rice and fish together has been a 2 000-year-old tradition in some parts of Southeast Asia (Halwart, 1998; Halwart and Gupta, 2004). The lowland societies of these regions of the world have been described as "rice–fish cultures", such is the importance and interconnection of these two basic food sources and production systems (Gregory and Guttmann, 2002). Rice-fish cultivation continues to be practiced in rain-fed and irrigated rice fields, and in upland terraced and lowland rice fields.

Rice-fish culture practices have demonstrated benefits in terms of increasing rice yields and also providing farmers with additional income. Implementation of a rice-fish culture system is relatively easy and an inexpensive culture strategy; in rice-fish culture strategies, fish are both cultured and captured as a by-product of rice cultivation, along with a wide variety of other aquatic organisms that contribute to local diets (Halwart, 2006). Both concurrent rice–fish culture in the shallower flooded areas and also alternating rice and fish culture in the deep-flooded areas of Bangladesh, through a community-based management system, have been tested and disseminated to farmers (Halwart, 1995; Dey and Prein, 2004) and with necessary local adaptations are considered suitable also for other regions in the world (Halwart and van Dam, 2006; Halwart and Settle, 2008). Organic rice cultivation practices combined with fish cultivation in paddy fields by the indigenous people (the Apatani tribe) in Arunachal Pradesh, India have shown the possibility of getting up to 5 tonnes of rice/ha and an average of 500 kg fish/ha. In this rice-fish culture system, farmers dig a small pond or trench in a low-lying area of the rice field that acts as a refuge for the fish during planting and harvesting or when there is little or no water. This system also allows farmers to keep fish alive after the growing season. Soil excavated is used to raise the dykes around the paddy field, which controls water levels and is also used to implement horticulture. Once the field is flooded, rice is planted, and once the paddy is established, fish are released. During harvest, water is drained and fish are collected. Some of the most relevant benefits of this integrated system include recycling of nutrients, increase in uptake of nutrients (e.g. phosphorus and nitrogen) by rice, increase in rice yields, reduction of dependence on external inputs such as fish feeds, chemical fertilizers and pesticides, reduction of pests, conservation of aquatic biodiversity, diversification of income-generating activities, income increase by farmers and increase in the availability of high-quality protein.

Traditional integrated aquaculture systems in India – policy interventions

Rice-fish culture implemented in intertidal brackishwater areas is prevalent in many countries, as will be described in several case studies in this paper, and it is geographically based on the locations adjoining the sea. In India, there are four geographical regions, with four different and specific integrated farming systems strategies being implemented as brackishwater rice-fish approaches, namely: pokkali paddy fields in Kerala, bheries in West Bengal, the khazan system of Goa and the gajani system of Karanataka (Jhingran, 1991-). These systems are still being implemented as efficient farming strategies adapted to very specific locations and as a way to provide an alternative and efficient use of brackishwater areas, thanks to specific farmer innovations developed to suit local conditions. The pokkali field, a unique ecosystem covering an area of 1 250 000 ha, is a traditional fish culture system in Kerala, India (Ranga, 2006). It is a shrimp culture filtration practice commonly known as “chemmeen kettu” and is normally practiced after rice harvest, but not always. The raising of fish and crustaceans in paddy fields, either together with rice or after harvest, is a very traditional practice. Wild shrimp and fish seed brought into the field through tidal water are trapped in the pokkali and allowed to grow for four to five months. In this system, no selective stocking or supplementary feeding is done. Vegetable wastes from the pokkali rice cultivation provide the required natural feed material for fish culture, meeting all fish requirements. At low tide, fish are caught in the sluice net. Trapped fish and crustaceans are harvested when they reach a marketable size. Nowadays, the pokkali paddy fields are not such a profitable venture, due to the increasing cost of human labour; nevertheless, since the flesh taste and quality of this specific production system are quite valuable and popular,, the system is being promoted and maintained by some governmental and private initiatives.

The bheri system is implemented nowadays in West Bengal. It is generally larger in size and based on a different type of location; this system is either used for rice-fish culture or for fish monoculture. Most bheries are used for fish culture using the Kolkata city domestic sewage as the feeding source (Nandeesha, 2002b; Edwards, 2008c). This technique of sewage-fed system is considered to be unique, and it is the largest system under sewage-fed fish culture in the world, utilizing domestic sewage as the primary feeding source to produce consumable products. The early success of fish culture in stabilized sewage ponds that were also used as a source of water for growing vegetables provided a stimulus for the large-scale expansion of sewage-fed fish culture. The area under this unique system of culture peaked at 12 000 ha; in recent years, there has been a steep decline in the total production area due to the increasing pressure from urbanization. However, the government has issued new legislation in order to conserve these wet lands and to prevent illegal utilization of bheries for urban settlements (Nandeesha, 2002b; Bunting, *et.al.,* 2004).

The khazan system of rice-fish culture is practiced along the coast of Goa, India, and is an example of a community-managed agriculture-aquaculture integrated ecosystem. The history of the system dates back to the sixth century (Sonak, Kazi and Abraham, 2005). This system was developed by local farmers who used their traditional knowledge on climate, tidal cycles, geomorphology, monsoon precipitation, runoff, sediment dynamics, soil properties and drainage characteristics of estuarine lands, in order to develop a suitable practice (Anon., 1992). The production system is located in the mangroves, which have been reclaimed using a system of dykes, canals and gates. The traditional and highly adapted khazan technology is based on the principle of salinity regulation and tidal clock. The system is currently under threat due to urban growth; thus, efforts are being made to preserve this traditional fish farming technology.

Periphyton-based fish culture

The acadja practice of West Africa was first described by Welcomme (1972) based on the practices followed in western African countries to capture fish through trapping by establishing periphyton-based food production systems. The most interesting aspect is that these periphyton-based practices have been developed independently in various geographical locations all over the world, following a very similar strategy. For example, similar methods are also prevalent in Asia and Latin America, such as the katha fishery in Bangladesh, the samarah fishery in Cambodia and shrimp and crayfish production in Mexico. The idea of using periphyton techniques in ponds, based on traditional farmers' practices, has attracted a wide research interest (Azim *et al.,* 2005). Bamboo stems, jute sticks, the remains of sugarcane stalks and tree branches are all used as the substrate. The aim of the practice is to increase fish production without increasing the level of nutrient inputs (Wahab *et al.,* 2001; Azim *et al.,* 2001; Keshavanath and Wahab, 2001; Verdegem and Azim, 2001). The practice originated from indigenous knowledge to attract fish, and fish farmers have found easy and feasible ways to understand its principle and apply it in aquaculture. Results clearly demonstrate the scope to increase fish and shrimp production by using the periphyton system and some of the progressive farmers are reaping the benefits through further on farm innovations.

Guinea Bissau: traditional integrated farming systems in mangroves areas

This traditional aquaculture system has been practiced in Guinea Bissau from ancient times and is based on the integration of the culture of indigenous tilapia species with rice production, mostly in brackishwaters located in mangrove areas. Farmers have applied their traditional and field-based wisdom on tidal cycles, sediment dynamics, soil properties and drainage characteristics of estuarine lands in order to develop a suitable integrated farming practice. There are two types of system being implemented in the coastal areas of Guinea Bissau: one system could be considered as the most ancient or traditional one and the second could be considered as the improved version of the traditional strategy. Fish harvesting is done once in a season, just after the rice harvest. The so called "traditional" system is based on the construction of a main dam and secondary dykes to regulate the entrance of seawater and to facilitate the storage of rainfall water into the rice field, in order to create a brackish environment appropriate for rice and fish culture. The main dam could be about 10 m in height, depending on the size of the field; secondary dikes also vary according to the dam's size. The antisalt dikes have three or four openings made by the trunks of palm trees and placed at the lowest point on the perimeter for evacuation and control of water in the rice field area. These antisalt systems have two main objectives: (i) to protect the rice fields against salt water brought by the high tide and (ii) to store rainwater in order to create favourable environmental conditions to culture irrigated rice.

The most common species being cultured are *Tilapia* spp. and *Clarias* spp., as both can tolerate high salinity rates. This "artificial" ecosystem created by rainfall water mixed with sea water decreases the number of predatory species less tolerant to low salinity.

The second type, the "innovative or improved" system, is based on the use of polyvinyl chloride (PVC) pipes instead of palm trunks for the openings and/or drainages, and wider and stronger dykes compared to the traditional system. Management principles remain the same. No supplemental feeding is done. This system is mostly located in the coastal regions in the south and northwest of Guinea Bissau (e.g. the region of Biombo and marine areas of northern and western Quinara and Tombali).

The major advantages of this traditional system are that the infrastructure, technology and inputs needed are available locally; that rice is the staple food for all communities in the areas concerned; and that there is a high concentration of producers in the same valleys which would allow communal management to be developed. Major constraints include that the system has to be technically sound and socially acceptable, and thus water management practices are needed – dams and dikes should be built solidly in order to minimize erosion; that the lack of technical information needs to be solved in order to optimize the culture system (e.g. biological information on species and production cycles); and that problems in accessing the rice fields during the rainy season need to be addressed.

Successful governmental approaches to documentation and validation of indigenous agriculture practices in India

The Indian Council of Agricultural Research (ICAR) undertook a major project to document relevant indigenous practices prevalent in various parts of the country, as well as to verify indigenous systems through scientific investigation. This massive study has resulted in the compilation of more than 100 agriculture-based indigenous strategies. However, this initiative didn't assess indigenous systems prevalent in aquaculture production (Das, et.al., 2004). Currently, a study by the Central Institute of Fisheries Education is documenting and validating relevant indigenous aquaculture and fisheries systems in different parts of the country.

Supporting farmers' innovations in aquaculture

Concepts and background

The term "innovative farmers" refers to those who have tried or are trying out new and often value-adding practices, using their own knowledge and wisdom but also through appropriation of outsiders' knowledge (Nandeesha, 2007). It has been recognized that farmers' innovations are crucial in order to achieve cumulative growth, both economically and socially. In most cases, farmers' innovations are encouraged by the need to maintain the economic viability of production systems. In other cases, social needs such as food security and increased income or cultural background are also drivers for innovation. Environmental sustainability, such as the desire to preserve or restore local species, has also been a driver of innovations in some regions (Reji and Waters-Bayer, 2001).

However, several social, political, economic and environmental factors have hampered farmers' innovation; these include a lack of quality information on aquaculture that will encourage farmers to engage in innovation, inadequate science and technology policies and a lack of governmental support. At the commercial level, fish farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology.

Innovation is a process that requires science to support technology development that is applicable to production. Proper design interventions and policies would help to bring much needed empathetic understanding and holistic vision to connect and integrate the various innovative efforts towards a positive outcome. These could provide vital directions for developing countries to transform into innovation-driven economies.

We have observed that some of the crucial factors to promote, encourage and support farmers' innovative processes are related to changes in science and technology laws, focused on promoting knowledge-based innovations. There is also a need for specific policies to enhance investment in innovation, educational policies to focus on developing specific profiles to manage technology-based aquaculture, appropriate personnel training and extension services, and policies that contribute to the development of aquaculture directed to specific social and cultural groups.

In this section, we present information on the major innovations that have occurred around the world thanks to farmers' initiative.

Farmers' innovations – the role of the Food and Agriculture Organization of the United Nations (FAO) in compiling and validating successful experiences

FAO provided the necessary forum and platform to share and discuss farmer innovations during the workshop on "Assessment of fish seed resources for sustainable aquaculture" (Bondad-Reantaso, 2007). Innovations related to fish seed production, with a special emphasis on women as producers, highlighted a number of innovations made by farmers in various Asian countries. This workshop pointed out that through productive partnerships between farmers and scientists, many technical issues can be solved by combining the field experience of farmers and the ability of researchers to access relevant information and develop intervention strategies. The study also suggested that documentation of farmer innovations from all over the world was very poor, and that the available information was weak and scattered. The possibility of establishing a database to include farmer innovations from all regions of the world was mentioned, to provide free access to stakeholders.

In this section, we have made an effort to capture significant innovations of farmers that have contributed to the development of aquaculture. There are several farmer innovations that can be tracked and classified as adaptive research; there are also path-breaking innovations made by farmers that have transformed the livelihoods of several thousands of farmers. These examples clearly demonstrate the success and sustainability of such innovations through partnership efforts.

Overview of the main innovations in China

Farmer's innovation in China may be traced back to its historical roots in the 5th century B.C., when Fan Li first tested culture of carps. The construction of earthen spawning ponds simulating the carp's natural environment is still a major technique used in fish spawning.

The polyculture system used in China has been refined and improved by Chinese farmers for centuries and is now a major culture system adapted worldwide. Scientific examination of the system has proven its superiority to monoculture in terms of ecological efficiency and environmental impacts. The eight-point management principles described below represent real farmer experiences and a wealth of knowledge; these principles remain applicable even today.

1) Water: clear, odourless, with good supply and drainage.
2) Seed: stocking large-size healthy fingerlings.
3) Feed: fresh, of high quality, palatable, digestible.
4) Control: feed fish on time at the same feeding spots with proper amount of quality feed; always pay attention to weather, water and fish.
5) Density: appropriate stocking density.
6) Multiple species: culture different species together with proper stocking ratio.
7) Rotation: undertake continuous stocking and partial harvest.
8) Prevention: good condition of water inlets and drainages; keep farm and ponds clean and free from contamination.

In such a system, new fish stockings can be done at virtually any time, taking into account the existing fish biomass in the pond. The partial harvest practices ensure that:

– harvested fish of multiple species have relatively large and unique size;
– fish supply to markets is homogeneous; and
– the pond has a relatively stable fish biomass.

Integrated farming systems evolved by Chinese farmers, particularly animal-fish integration, have had a remarkable impact globally, but particularly on poor and vulnerable farmers. It should be noted, for example, that rotational harvest, i.e. undertaking continuous stocking and harvesting, greatly improves fish yield as compared to single-harvest procedures.

It is important to note that Chinese aquaculture is gradually moving into a feed-based monoculture intensive system, largely focussed on one or two species. While the sustainability of these market-driven interventions would be based on market economics, integrated systems will continue to provide economic advantage to poor rural and urban fish farmers. Regarding future trends and major constraints, improving fish safety and the efficiency of integrated systems should be among the main foci through appropriate and field-based scientific interventions.

Aquaculture in China is now moving towards increased systems and species diversity, as well as increased productivity (Edwards 2008a, 2009d). Apart from modern monoculture, such as intensive shrimp culture, aquaculture systems in China vary in terms of inputs and management, and change greatly due to geographic and weather conditions. Farmers in China are extremely flexible and adaptive to their own natural, social and economic conditions and continuously modify their aquaculture systems to suit local conditions, using their own field-based knowledge. Research results are often at the background, and farmers' application of these results is blended with their own ideas. The excellent partnership between farmers and researchers in this country has favoured the rapid uptake of research outputs by farmers, who adapt new technologies to local conditions. The entrepreneurial nature of Chinese farmers, aimed at meeting the increasing demand for aquatic food, has contributed to the rapid development of culture techniques. For each farming strategy and for each species being cultured in China, there are several innovations which could be described and documented in detail.

Carp culture innovations in Andhra Pradesh, India

Farmers in Andhra Pradesh have revolutionized carp culture by introducing it in rice production areas. Path-breaking farmers' innovations in terms of practices related to seed production and feeding strategies in Andhra Pradesh have been documented by many authors (e.g. Nandeesha, 2007; Ramakrishna, 2007; Edwards, 2008b; Roy, Saha and Kumaraiah, 2008). Carp culture was introduced around 1976 in Andhra Pradesh and expanded rapidly and intensified between 1985 and 2005. At present ,, the commercial culture of Indian major carps is undertaken by farmers in an area of about 90 000 ha, with all production being carried out in earthen dug-out ponds. As previously mentioned, many of the innovations related to feeding and culture practices have been documented in detail, including the most recent innovations of farmers regarding the use of much larger-size seed for early culture systems. The most significant innovations are related to species composition and polyculture strategies; these involve the culture of three commercially important species, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal carp (*Cirrhinus cirrhosus*), instead of the six species that have been normally recommended for polyculture by researchers. Another relevant innovation and improvement has been the change of stocking rate for species like *Labeo rohita* increasing it up to 90 percent of inclusion level, in view of its market demand. Also, instead of using small-size seed, farmers have developed the technique of using stunted seed that are aged but have not attained a weight proportionate to their age, and stimulating their rapid growth in a limited period of time by compensatory growth effect.

Regarding feeding strategies, farmers have developed a simple feeding method called "the bag feeding technique" whereby the feed is kept in feed bags with small perforations that may be arranged in two to three rows. Indian major carps have the habit of browsing, sucking the feed through perforations. Just by using these simple adaptations – flushing stunted seed, fertilizing ponds to produce an adequate amount of natural food and feeding through feed bags – farmers reached an average production of 8 tonnes/ha/year, with a maximum production of up to 15 tonnes/ha/year.

In order to reduce the culture period and increase the number of crops per year, farmers are now stunting the seed for more than one year and then fattening them to 200–300 g before stocking into the earthen culture ponds. Commercial culture of these fish is called "zero point culture", the name being derived from the fact that the stocked fish have not attained 1 kg weight prior to stocking. These fish would attain a 1 kg weight in 5–8 months, depending on the density and the resources used. Farmers have also developed innovative transportation and distribution systems for the movement of these large fish, since there is a separate group of farmers who have specialized in producing and distributing zero-point stock size fish. Farmers have used the available water storage tanks of 1–2 tonne capacity to stock fish and transport them by using continuous oxygenation.

With nearly 90 000 ha devoted to carp culture, a production of over 0.7 million tonnes, and considering that there is a limited consumption of fish in the state, farmers have developed cost-effective transportation, packing and distribution systems to transport marketable fish to other regions of the country, which reflects the innovative potential of farmers at each stage of the value chain.

A meticulous distribution and cost-efficient planning mechanism, based on their own research, has been developed in order to supply fish, based on orders. The entire production cycle is structured around the market demand. In the beginning, farmers used bamboo baskets for packing and transporting, but later switched to plastic trays; nowadays, plastic trays with insulated trucks are used to transport fish, not only to different parts of the country but also to other countries in the region such as Bangladesh and Nepal (Ramakrishna, 2010).

Freshwater prawn culture innovations in Bangladesh – technology transfer through a farmer field school approach

Bangladesh, a very densely populated country with serious problems pertaining to food security and nutrition, as well as poverty, has been focussing on a more efficient and sustainable use of its available and limited natural resources, such as water, land, feeds and seed, in order to improve the general food security situation and increase and diversify income-generating activities. There have been many relevant innovations made by fish farmers all over the country; these have already transformed the sector, and the country is recognized for its accomplishments with regard to efficient and diversified aquaculture production. In southwestern areas of Bangladesh, floods and droughts have been common problems, and farmers have been looking for alternative crops to rice, in order to improve and secure their income. A few years ago, a very innovative and progressive farmer of this region started to integrate rice production with giant river prawn, *Macrobrachium rosenbergii*, culture in unproductive paddy fields. This system evolved and was adopted successfully by many farmers within the same region. The system, popularly known as *gher*, has transformed the lives of several thousands of families, providing them with a very high and stable income through prawn cultivation. In the gher system, a canal is dug all around the paddy field, comprising 40–50 percent of the area, and the central portion is left undisturbed to undertake paddy cultivation. The soil excavated for the canal is used to make large dykes, in order to prevent flooding problems.

The major bottleneck nowadays is the availability of freshwater prawn seed, which is mostly collected from the wild; availability of seed spurred the rapid development of prawn farming, and there are several thousand farmers engaged in collecting postlarvae from natural waters. Few hatcheries have been established to cater to the seed requirement, and it is reported that wild-collected seed continue to be preferred by farmers (Nandeesha, 2003; Ahmed *et al.,* 2007; Ahmed and Troell, 2010).

Postlarvae are stocked in the canal and are nursed to the juvenile stage in pockets created in the canal by erecting small dykes. With the onset of monsoon, when the water fills the canal, postlarvae are spread to the entire area. In the past, farmers cultivated only one crop of paddy during the dry season, under the assumption that cultivation of paddy during the monsoon would negatively impact the growth of prawn; even in places where there was a potential, farmers did not cultivate a second crop. At present, with the educational programs provided to farmers, more than one crop of paddy is grown by good number of farmers.

The stocked prawns are fed largely with snail meat, in view of its ready availability in the area and its easy acceptance by prawns. Prawns are reared for a period of six months, and are harvested based on the average size and sold to processors. Total production ranges from 200–500 kg/ha. Thanks to the high price of prawn in the market, farmers have been able to earn good incomes, even with this small production.

The technology spread very rapidly in view of the good financial benefits farmers can derive by culturing prawn, which has high demand from the processing industry for export. However, due to inadequate technical support to farmers in planning their activities, some farmers ended up losing money and in some cases, total crop failure occurred with a disastrous consequence for the family.

Several non-governmental organizations (NGOs) have now stepped into this specific sector, providing technical support to farmers with the aim of defining their activities in a more sustainable way. CARE Bangladesh undertook a relevant project aimed at organizing farmers into clusters and empowering them with knowledge and skills by using a farmer field school approach. By adopting this experimental and field-based learning strategy, farmers were assisted to make good production plans that included stocking the proper number of postlarvae, raising them to juvenile stage by giving quality feed, raising these juveniles to market size by using homemade feed instead of using only snail meat, raising two crops of paddy comprising a dry season crop followed by a wet season one, using the large amount of available dyke space for cultivating vegetables, making financial plans to ensure adequate profitability and involving women in the entire crop cultivation process.

By adopting several of the practices mentioned above, farmers were able to improve prawn production substantially and earn additional income from the growing of vegetables in the dyke space. This integrated approach assisted several thousand families in substantially improving their incomes. This technology, which evolved in the southwestern part of Bangladesh, has now spread to other parts of the country, where farmers are now cultivating prawns along with rice and obtaining substantial income. It is reported that farmers who were earning only about USD80–100 by cultivating only rice are now able to earn over USD500 by adopting this integrated approach. With the establishment of several hatcheries devoted to the production of freshwater prawn seed, the use of hatchery-produced seed is gaining gradual prominence. The establishment of a very functional network for harvesting and distributing prawns in good conditions, either for marketing or processing, has helped farmers to continue the activity in a more sustainable and efficient way. The impact of this innovative technology has been very high and has contributed immensely to poverty alleviation. It is reported that Bangladesh is exporting 23 000 tonnes of freshwater prawn nowadays, which is around 11 percent of the global trade of this species (Ahmed, 2010).

Innovations in pangasiid culture in Viet Nam

The technology for the culture of pangasiid catfishes was initiated by the farmers in the lower Mekong region, particularly in Viet Nam and Cambodia. Among the 18 species, two species were and are widely cultured: “basa” (*Pangasius bocourti*) and “tra” or striped catfish (*Pangasianodon hypopthalmus*). The culture of these fish in ponds and cages has provided employment and improved food security to several thousand people (Nandeesha *et al.,* 1997; Phuong and Oanh, 2010). While the culture of *P. bocourti* is limited, striped catfish culture is widely practiced by farmers. In the past, farmers used to collect wild-caught seed from the Mekong River, culturing them to marketable size in ponds or cages by feeding mostly with small fresh fish during the rainy seasons and dried fish mixed with rice bran during rest of the year.

In Cambodia, farmers culture striped catfish and have been able to obtain a production of up to 100 tonnes/ha/year. Seed are stocked at 5–6 fish/m^2 and are fed with cooked rice bran mixed with 10–15 percent dry fish during most of the year. However, during the fishing season, when fresh fish is available in abundance for two to three months, farmers feed them with small fresh fish or low-value fish as the main feed. With negligible amount of water exchange, farmers have been able to obtain production ranging from 40–100 tonnes/ha/year, based on the level of management strategies adopted.

Efficient and feasible breeding strategies, in combination with appropriate larval rearing techniques for striped catfish, developed by Vietnamese scientists in partnership with French and Norwegian collaborators, have led to a huge development of both the seed and table fish production industries. Currently, good amound of seed are easily available throughout the region. Related farmers' innovations regarding culture practices in general, such as stocking densities, feeding strategies and rates, pond preparation and maintenance, harvesting, fish processing, fish distribution and exports have also led to a rapid and extremely efficient development of the sector. Vietnamese farmers are currently exporting large amounts of striped catfish to western markets. Through these export opportunities, farmers in Viet Nam have developed a very intensive production system by using ponds of 3–5 m depth and by stocking at a rate of around 20–30 fish/m^3. Due to the high cost of land in the delta area, farmers have made use of the air-breathing physiology of the fish in order to intensify the culture by increasing the density based on the volume of water in deeper ponds, coupled with regular exchange of water. This has helped farmers to produce a higher volume of fish within the same pond area, by stocking based on the entire volume of water available in the pond.

Through adequate water exchange practices, farmers have been able to produce fish that meet the quality requirements of the processing sector, producing high-value-added products to meet the export market demand. Stocking of fish based on the total volume of water available in the pond is a major innovation made by farmers along the Vietnamese Mekong Delta area. Further, farmers have developed knowledge of the volume of water to be exchanged to produce quality fish. While some farmers still use homemade feed, the availability of quality floating feed has helped farmers to improve productivity by increasing the stocking density and feeding rate. All these factors have helped farmers to obtain an average yield of 400 tonnes/ha/crop for a rearing period of 6–7 months (Phuong and Onah, 2010).The processing sector has also been very innovative in terms of value-added product diversity and has diversified the export market to include nearly 80 countries.

However, the industry is also facing many challenges due to this intensive intensification process, such as increased disease incidence and outbreaks, as well as increasing feed costs. As the investment cost per hectare increases, the risk that small farmers have to face is very high. Although net return per hectare is reported to be high as compared to other species, farmers face great difficulty in carrying out this activity in a sustainable manner.

Among major challenges and future constraints, this fast-developed industry requires urgent scientific intervention in strong partnership with farmers to address the major challenges encountered. These include:

- *the declining quality of the available seed* – This is one of the major constraints reported by farmers. Hatcheries have taken up seed production and produce seed to meet the demand, but without any concern for quality. Appropriate broodstock management practices are lacking and inbreeding is a major limitation; brooders are repeatedly used for seed production during a season, and there is no exchange of brood stock on a regular basis with the wild-caught brood fish;

- *the increasing cost of feed* –This is a major concern, with more than 60 percent of production cost being attributed to feed. Producing quality feed at an affordable cost by using adequate feed formulations requires scientific interventions applying farmers' field knowledge; and
- *the huge gap between the farm gate price and the consumer retail price in various countries* – Reducing the difference would require market innovations and policy support.

The government has been quite proactive in supporting the Vietnamese catfish production industry by providing an appropriate legal framework, adequate policies and other enabling supporting structures. As the government has placed heavy emphasis on earning foreign exchange through exports, special support facilities for the production, processing and export sectors have been also provided.

The National Research Centre and Can Tho University, located in the Mekong Delta region, have not only acknowledged the farmers' innovativeness, but have also provided support to improve technology and disseminate farmers' innovations by establishing partnerships with entrepreneurial farmers. The government has also been providing research support through the national institutions to carry out technical studies on various issues. The Network of Aquaculture Centres in Asia- Pacific (NACA), an intergovernmental organization, has initiated a major programme to support farmers in developing better management practices (BMPs) through farmer participatory research.

Farmers have reached a point where further progress and sustainability will largely depend on the quality of scientific input. With the commercialization of the activity, there are challenges to carrying out on-farm research with farmers, but these are addressed in the process of developing BMPs. The success accomplished in Viet Nam has not been replicated elsewhere, and it is unlikely that such a level of production would become possible without adequate water availability. However, the species is gaining importance in countries such as Indonesia, Cambodia, India and Myanmar, with the aim of meeting domestic market demand and exploring new options

Seed production innovations in Cambodia

Cambodia has witnessed rapid growth in aquaculture in the past decade. The Tonle Sap Great Lake, which is known as a geographical wonder for its ability to become filled in the monsoon and emptied during the dry season, with an area fluctuating from 3 000 to 10 000 km^2, is the major location for aquaculture and capture fisheries production in the country. People living around the great lake are known to consume some 70 kg of fish/person/year. Rice-field fisheries and aquaculture systems, as well as fisheries activities in the Mekong River and its tributaries, also contribute to the fisheries sector in the region. However, with the Cambodian population increasing at a rate of 3 percent per year and capture fisheries declining rapidly, it is predicted that the availability of fish per capita will decline if adequate steps are not taken to promote village-based fish culture systems. Recognizing this need, governmental agencies and NGOs have initiated programmes to promote fish culture since the 1990s. Where these programmes have focused on the promotion and development of small-scale aquaculture, they have demonstrated the rapid acceptance of the activity and the active participation of farmers in generating technologies adapted to their own local circumstances. Farmers have made innumerable innovations in Cambodia during these years, for example, with regard to feed production and feeding and fertilization strategies by using locally available raw materials and resources, such as terrestrial worms, aquatic macrophytes and snails as alternative protein sources. Farmers have been able to reach productions of up to 4 000 kg/ha/year in some locations, just by innovating and adapting small-scale aquaculture technologies developed in other regions of the world to suit their own needs and environment.

Major innovations have taken place regarding seed production and distribution, since the availability of good quality seed was one of the major constraints for aquaculture development in isolated and vulnerable areas. In order to sustain aquaculture development, decentralized seed production activities were initiated from the early stages of these previously mentioned projects. Innovations made by farmers in developing small-scale seed production technologies using local materials and traditional knowledge to establish classical Chinese-style hatcheries for floating eggs clearly demonstrate the innovative capacity of farmers when resources are extremely limited. Farmers, after learning the principles of Chinese hatchery operations, designed least-cost production units by using plastic sheets to line excavated earthen ponds in order to simulate the spawning area of the Chinese hatchery. Such earthen Chinese hatcheries have been successfully used for breeding and hatching for years, and with a great success in many locations. In most cases, thanks to the income generated from seed sales, producers have improved the hatcheries by using more durable materials.

Several designs of these Chinese hatcheries have been successfully built by farmers in different parts of the country (Nandeesha, 2002a, 2007; De Labra, 2008). They have been able to breed most of the cultivated carps, silver barb (*Barbonymus gonionotus*), catfish and even freshwater prawn. At present, it is estimated that over 100 hatcheries are operating in different parts of the country to meet the seed requirement of the farmers.

Aquaculture development in the northern provinces of Cambodia

The northern provinces of Cambodia, comprising Ratanakiri, Mondulkiri, Stung Treng and Kratie, are extremely isolated and mainly inhabited by indigenous people from a broad range of ethnic groups. Although these provinces are rich in natural resources, poverty and food insecurity are more acute than in the rest of the country, mostly due to low agricultural productivity and the inefficient use of natural resources. Rural households located far from the Mekong River and its tributaries face real problems related to a low intake of high-quality protein and poor nutrition. Recently, these provinces have been targeted by several Spanish agencies in order to promote and develop small-scale aquaculture practices by improving and disseminating existing indigenous knowledge and practices, such as periphyton-based fish culture techniques in earthen ponds, community fish pond management and early larval rearing in small waterbodies. Interestingly, the response by farmers to improving their traditional techniques and adapting them to current local conditions has been very strong; fish farmers have become extremely implicated and motivated to grow fish successfully. Since the beginning of the programme, innovative dissemination strategies have been adopted in order to involve ethnic groups in the decision and learning processes. Through the innovative extension strategies adopted, farmers have been successful in obtaining good production using local resources available on the farm; rice-fish culture technologies have been well received by the farmers. As these provinces are located far away from the active seed production provinces, small-scale seed production technology has also been introduced in this area. Farmers have successfully adapted Chinese hatchery systems for floating eggs to meet the local demand; currently, most of the seed needed to assure a sustainable production has been produced in these small local private-scale hatcheries (De Labra, 2008).

Carp culture innovations in Myanmar

Myanmar has emerged as a major carp producing country in Asia. Several thousand hectares of carp farms have been established in the country, and it is reported that over USD80 million was made through the export of carps in 2008. The carp culture development in Myanmar resembles the situation prevailing in India, in terms of major innovations. Farmers in Myanmar have also evolved the existing technology for labeo roho culture (as the dominant species), and obtain a production of around 8 tonnes/ha/year. Stunted seed of 8–12 months and a weight of 50–100 g are stocked into large-size ponds and locally made supplementary feed applied. Unlike in Andhra Pradesh, where fertilization with both organic manures and inorganic fertilizers is used heavily, in Myanmar, supplemental homemade feeds and artificial feeds play a major role. Fish are stocked at 8 000–10 000 individuals/ha and grown for a period of one year. Fish are fed with rice bran and oil cake mixture, which has become very popular during these last years. Fish are harvested after they attain a weight of over 1 kg and then sent to market. These fish are either packed on ice and sent to Bangladesh for sale or processed by degutting and freezing, and exported to various countries, mainly in the Middle East (Ng, Soe and Phone, 2007).

Most of the seed supply required to maintain the sector is produced within the country, and efforts have been made to improve the genetic quality of fish through selective breeding programmes. For example, a pink-colour strain of labeo roho has been developed which seems to have higher growth rate, better flesh quality and a desirable appearance. Although farmers have not been able to achieve good survival rates at the hatchery and nursery stages, they have been successful in producing at least the minimum required amount of seed to meet the country's demands.

Farmers' innovation in the culture of catfish, tilapia and shrimp in Thailand

Thailand has rapidly emerged as a major aquaculture-producing country thanks to the innovative nature of its farmers, combined with their entrepreneurial approach. In the freshwater aquaculture sector, there have been many farmers' innovations regarding the culture of catfish (*Clarias batrachus*), as well as the culture of hybrid catfish (*C. macrocephalus x C. gariepinus*). The efficient use of selected males of North African catfish (*Clarias gariepinus*) for artificial breeding and egg fertilization has been a real constraint for many years, and due to this reason, Thailand's farmers have developed a more sophisticated method whereby sperm is partially collected through an easy "surgery" procedure, after which males are released and can be used again for several times, after adequate recovery. This simple "surgical" method has become very popular in all regions of the country, and farmers have been able to save money, develop adequate selective breeding programmes at a small scale and improve operational efficiency (D. Little, unpublished).

Tilapia production in Thailand has increased notably in the past years, due to the innovations developed by farmers regarding seed production and distribution, through the establishment of quite successful seed producers' networks and clusters all over the country (Little, Kaewpaitoon and Haitook, 1994; Little *et al.,* 2007). These seed producers' networks exchange experiences and information between farmers and improve technology transfer. Thanks to establishment of these clusters and the successful exchange of information, a number of innovations have been made to hatchery and nursery management practices and technologies in order to improve operational efficiency (Bhujel, 2008). In both tilapia pond and cage culture, farmers have also adapted technologies from other regions of the world to their own local conditions in order to remain economically viable.

Regarding the culture of whiteleg shrimp (*Litopenaeus vannamei*) in Thailand, there is an innovative farmer, Mr. Banchong, who has built a hatchery close to Bangkok, about 60 km from the sea. He is has been using a very efficient and environmentally friendly recirculating system for more than eight years, involving water filtration, extraction of undesirable nutrients by using aquatic macrophytes in a treatment plant (reducing biological oxygen demand (BOD) and reusing treated filtered water for hatchery purposes. This farmer is also using the sea water to produce *Artemia* nauplii for use as live feed by using good-quality brooders collected from the field. Through the implementation of appropriate biosecurity measures, this farmer is producing around 600 million nauplii/month. By using a recirculating water system, he is reported not only to be preventing disease outbreaks and major biosecurity constraints, but also to be saving the huge cost on water transportation (Kongkeo, New and Sukumasavin, 2008).

Farmers' innovation in freshwater and marine finfish larval rearing in Indonesia

Indonesia is another country that has registered rapid growth in aquaculture and has made breakthroughs in the breeding and larval rearing of several freshwater and marine finfish. Farmers in Indonesia are reported to obtain over 50 percent survival in the larval rearing of striped catfish, while it is still low in the Mekong region. By adopting effective feeding strategies and regimes to prevent cannibalism in the early stages, farmers have succeeded in achieving higher survival rates. The rapid development of the seed production industry for tilapia and common carp (*Cyprinus carpio*) has contributed to the rapid growth of the aquaculture sector as a whole (Edwards 2009a,b,c, 2010a,c,d).

Regarding marine finfish larval rearing technologies, farmers have been successful in establishing backyard hatchery systems. By using these facilities, farmers have been able to procure sufficient eggs and fry, and rear them until they are able to reach marketable size. In the case of milkfish (*Chanos chanos*), the Gondol research station recommended a set of facilities and practices in order to achieve adequate results in larval rearing, such as use of larval tanks, tanks for the culture of phytoplankton (*Nannochloropsis oculata*) and rotifers covered with appropriate roofs, feeding of larvae with rotifers followed by artificial feed, and rearing the larvae for 21 days. Once the farmers started the culture operation, they modified the technology to reduce costs by culturing larvae and plankton without any roof. Furthermore, some farmers started culturing rotifers by using trash fish, so that no artificial feed was required. By adopting this modified technology, the larval technology described with economics by Sugama, Saidah and Sunaryanto, 2006 has been modified and rearing period has been reduced to 15–16 days, instead of 21 days.).

Another example is the success achieved by farmers in Indonesia regarding the breeding of humpback grouper (*Cromileptes altivelis*) and brown-marbled grouper (*Epinephelus fuscoguttatus*) in order to increase the production of these highly demanded species (many farms in the country depend on the culture of these high-value species). Larval rearing of these species poses many challenges. While research stations advocated the use of artificial feed during larval rearing, farmers started to successfully use small shrimp and available low-value and trash fish. Furthermore, they started culturing the larvae in earthen ponds instead of concrete ponds or hapas, and this new system enhanced surprisingly both survival rates and growth. These successful adaptations made by farmers have contributed to the increased availability of larvae for culture.

Catfish culture and market-driven approach innovations in Nigeria

Fish is an important component of the diet of many Nigerians. With fish imports making up more than half of the supply, the Nigerian Government seeks import substitution through different programmes targeting increased domestic fish production, particularly through aquaculture promotion and development. The Nigerian experience involves several key innovations that launched commercial and market-driven fish farming within the country.

There are 15 hatcheries supplying enough high-quality seed to fish farmers. Farmers' innovations focused on maintaining stock quality and fingerling supply to market-oriented growers have triggered the growth of the sector, including the privatized extension support system. There are over 100 innovative farms that produce fish efficiently using high-quality seed of known origin, considering growth rates, flesh quality, disease resistance and high stocking density tolerance, among other traits. Technical support services provided by several private, public and semiprivate professional organizations such as the Fishery Society of Nigeria (FISON), the Catfish Farmers Association (CAFAN) and the Federal Department of Fisheries (FDF) have stimulated the healthy growth of the industry, and most farms are already integrated with seed and feed producers within a broad holistic approach. Given the availability of high-quality seed and feeds and the use of appropriate strategies for dissemination of proven technology, the aquaculture sector is expected to develop as a long-term, sustainable food-producing sector within the country.

Aquaculture development and farmers' innovations in Uganda

Ugandan aquaculture has seen a revolution, moving from an annual production of 285 tonnes in the early 1990s to 72 800 tonnes in 2008. Although the majority of fish farmers remain smallholder practitioners, the goal for aquaculture has changed, and this has lead aquaculture to become a key production enterprise in Uganda, with an incredible annual growth rate of nearly 300 percent over the last ten years. Aquaculture production has quickly evolved and expanded to include not only small-scale fish farmers but also medium-scale farmers producing purely for external consumption through effective marketing.

A change in government policy in 2001 to move aquaculture from a livelihood approach to a market-driven strategy has changed the growth pattern of aquaculture. As the first step to provide quality seed, commercial hatcheries were encouraged to develop appropriate breeding and feeding strategies and coherent and well-implemented holistic biosecurity protocols highly adapted to the Ugandan context. Further, from a strictly pond-based system, aquaculture was moved to other innovative approaches, taking into account the specificities of the country in terms of the availability of water, land and other inputs; traditional agrolivestock practices, etc. During the last few years, innovative farming systems have been developed to increase efficient production; these include cage, pen and recirculating systems. The establishment of aquafeed factories within the country, using adequate diet formulations and available raw materials has been essential to promote the industry and has strongly facilitated the healthy growth of the sector. Most importantly, capacity building of extension staff at the public, private and semipublic levels and institutional strengthening to promote farmers' learning through on-farm discovery, validation and analysis has helped the aquaculture sector to grow by making information and technology available to farmers in isolated areas. Skilled workers are essential for the promotion of new activities such as aquaculture. Through support to farmers, local development partners and the government, donor agencies have played an important catalytic role for aquaculture development through innovations since the beginning of the sector.

Australian freshwater crayfish culture innovations in Ecuador and Mexico

The culture of the Australian freshwater crayfish or redclaw (*Cherax quadricarinatus*) provides a good example demonstrating the innovative potential of farmers. Although still a small industry in Australia and several Latin American countries, redclaw culture was originally developed from farmer to farmer technology transfer.

Culture was initially developed in small-scale family operations as a hobby or for personal consumption. The relative ease of extensive production in large dams or man-made lakes encouraged some investors to attempt commercial production. A few farms became suppliers of juveniles for new farmers. These farmers would provide information of "best-known practices" through monthly newsletters. As a result, this cottage industry grew, with a reported production of 60 tonnes/year during the 1980s.

Due to the cannibalistic nature of the species, the development of culture techniques based on refuges or "hiding places" was necessary. Farmers in Australia found that old, discarded car tires could be obtained at no cost, so they used them to provide refuges for redclaw. This allowed for a more consistent survival in the ponds and yields of 1.5 tonnes/ha. In Ecuador, tires were not an option, as they are retreated and re-used, so local bamboo was cut to an adequate length and bundled together to provide hiding places. These bamboo bundles were easier to use, which helped improve yields (2 500 kg/ha), reduce manpower needed to set a culture pond, and facilitated drainage and pond cleanup. Nevertheless, bamboo tended to rot after two or three production years, thus creating a medium-term problem. For this reason, farmers began using cement bricks as hiding places. These allowed for consistent pond set-up, eliminated the impact of decomposing bamboo in the pond (which helped yields), and reduced total organic matter in drain water, thus reducing the impact on the environment.

Farmer innovation on the original production technology is also evident in terms of juvenile production. Farmers in Australia developed the use of onion-bag bundles to protect small juveniles in the ponds from cannibalism and to harvest them from ponds. In Ecuador and Mexico, the systematic use of onion-bag bundles allowed farmers to harvest juveniles and select for size more efficiently, increasing yield and reducing production cost per juvenile.

Similarly, the lack of basic knowledge on the nutritional requirements of the species did not prevent Australian farmers from cultivating the crayfish. Good growth rates were obtained by supplying them with a variety of locally available feedstuffs, such as boiled potatoes and carrots, pelletized barley and chicken-layer pellets. Daily observation even allowed farmers to realize that redclaw would actively seek several feedstuffs, such as boiled corn cobs, near the edge of the pond at night, which helped the farmer to determine size the of the organism and the feeding demand and even allowed for the trapping of some examples for personal consumption or small volume sales.

Attention to species behaviour in the pond also helped farmers design more efficient harvesting methods, such as the flow trap, which works on the principle of counter-current freshwater attracting crayfish out from stagnated pond water. This allowed for systematic “self-harvesting” of the crayfish at night, thus reducing manpower requirements and limiting the impact of workers’ feet on the pond bottom and crayfish being stepped on by farmers during “hands-on” harvesting.

Indigenous species culture innovations in the Tabasco region, Mexico

Tabasco possesses one of the main wetlands in Mesoamerica, Reserve of the Biosphere, Pantanos de Centla, with 305 000 ha where the Grijalva and Usumacinta rivers come together, adding nutrients to associated estuaries, lagoons and coastal zones, helping important fisheries for fish (e.g. sharks, rays, snooks, red porgy, pompanos, mackerel, cutlass fish, gars, native cichlids), crustaceans (shrimp and river prawn) and bivalve molluscs (American cupped oyster, *Crasostrea virginica*). Capture fishery is thus the primary activity of the rural populations living in proximity to these ecosystems, due to its relative ease and low production costs.

However, aquaculture production and research on the culture of native species are being actively promoted as an alternative to capture fisheries. The native species being cultured following innovative approaches are: tropical gar (*Atractosteus tropicus*), bay snook (*Petenia splendida*), Mexican mojarra (*Cichlasoma uropthalmum*) and common snook (*Centropomus undecimalis*). Studies on tropical gar have placed this specific research group on the international forefront with regard to the generation of basic knowledge applicable to biological conservation, culture technologies for meat production, and the production of ornamental fish by aquaculture.

Efforts have been made to develop culture technology for the native species using many of the rustic ponds available in rural areas. Scientists from the Tropical Aquaculture Laboratory have provided the technical support to stimulate farmers' involvement in developing technologies through adaptive research. Using a market approach, an exploratory study was conducted to examine the four characteristics of tropical gar consumption in the Tabasco region, namely (i) economic importance, (ii) presentation, (iii) quality and (iv) traceability. The study was implemented in 50 restaurants. The most important results show that tropical gar represents an average of 10 percent of total sales, that its availability is seasonal, and that it is consumed mainly in grilled form. The results indicate that tropical gar has an important nutritional, economic and cultural value in Tabasco. This type of exploratory study can be used to evaluate consumption of other native species and understand the market requirements, and based on such studies, technological interventions could be planned to develop an efficient and sustainable tropical gar industry.

40 years of innovations in shrimp culture in Mexico

The shrimp culture industry in Mexico has generated many adaptations and innovations by farmers in order to develop the best breeding and farming practices. The legal framework developed by the government has enabled a coherent and regulated growth of the industry, maintaining its long-term sustainability and even overcoming most of the challenges posed by the shrimp farming sector at the social, economic and environmental levels.

Although the industry started collecting seed from the wild, by the year 2 000 there were practically no farms using wild-caught larvae for aquaculture purposes. The last decade witnessed the development of hatcheries with strict biosecurity protocols to ensure healthy seed production; thanks to this approach, the sector has become wide-spread.

Although initially blue shrimp (*L. stylirostris*) were used, whiteleg shrimp (*L. vannamei*) is the most commonly cultured species, as it is adaptable, easy to breed and has higher tail yield.

Innovations made on pond design for effective filling and drainage of water and on pond shape to facilitate strategies for easy harvesting have contributed to increased production. An important progress was the construction of breakwaters and pumping stations out on the open sea. Almost without exception, farms collected their water from estuaries or coastal lagoons with low hydrodynamics, but this posed a limit to future expansion of the sector. Once free of these constraints, large land areas with coastline proximity were finally adapted to shrimp culture.

Further, feeding efficiency was increased in many ways through optimization of feeding strategies, such as an increase in the number of daily feedings to four per day. To maintain better water quality, special aquaculture fertilizers and probiotics were used. Stocking densities were increased from 10–12 postlarvae/m^2 to 40 postlarvae/m^2, which is the optimal stocking density used today by many farms.

Innovations regarding indigenous species culture in Colombia

Aquaculture is growing rapidly in Colombia through the successful linkage of farmers and research institutions. Farmers are closely assisted by scientists through on-farm validation and appropriate dissemination technologies. The success achieved with the culture of Nile tilapia (*Oreochromis niloticus*) and red tilapia has prompted the farmers to explore the culture of these species integrated with other native species that are very popular in local markets, such as dorada (*Brycon moorei*), netted prochilod (*Prochilodus reticulatus*), cachama (*Colossoma macropomum*) and pirapatinga (*Piaractus brachipomus*). The joint initiative of the Outreach Station of Caldas University and farmers has led to a number of farmers' innovations. Some of the most relevant innovative strategies which have already made very significant impacts include: polyculture of tilapia with native species, development of greenhouse technologies to regulate temperature during the winter, development of aquafeeds using local raw materials and resources, development of sustainable fertilization technologies, supplemental feeding strategies, and the establishment of recirculation systems using hydraulic power.

The study's results clearly demonstrate that the involvement of the community and the research centers (in partnership) in the needs identification process within the aquaculture sector is extremely fruitful; planning and initiative development based on such identified needs will hasten the development process.

Dissemination of success stories – case studies

Information dissemination has been one of the major constraints which continues to hinder the development and the transfer of technology in many ways. However, with the introduction of new methodologies in the field of information technology, it is now possible to distribute and disseminate information globally in an affordable way to many developing countries. Information dissemination alone will not bring major benefits unless there are people with the necessary capacity to absorb the knowledge disseminated and build skills and transfer knowledge into practical benefits. In this section, examples are presented of how institutions and communications and dissemination tools have helped in transforming the aquaculture sector in the past decade.

Genetically improved farmed tilapia (GIFT) and its impact

The application of genetics tools in aquaculture is still very limited as compared to plant and livestock production. The WorldFish Center made a maiden effort to apply quantitative genetics principles to improve growth performance in farmed tilapia. Although Mozambique tilapia (*Oreochromis mossambicus*) has been viewed negatively in most parts of Asia, the Nile tilapia (*O. niloticus*) is considered as a boon for both the poor and the rich, in view of its flesh quality and ability to grow in different environments. Since most of the countries cultivating this species were experiencing poor growth performance, mostly due to the small gene pool within the population that was used for seed production and culture, the WorldFish Center decided to undertake this major project with the support of the Asian Development Bank and in collaboration with other partners such as AKVAFORSK from Norway, in order to develop a genetically improved strain of tilapia. In this project, stocks were collected from four countries in Africa, namely Ghana, Senegal, Ivory Coast and Egypt, as well as from four Asian countries, i.e. the Philippines, Singapore, China and Thailand. These stocks were cross bred through family selection as well as within family selection. Twenty-five different base populations were used to evolve the best possible strain through a traditional quantitative selective breeding process.

The strain that was developed for years through this selective breeding process has been disseminated to a number of countries in Asia by following suitable guidelines and training procedures in order to prevent possible negative impacts on the environment and achieve the best results. The stocks have been introduced to Bangladesh, Ivory Coast, Egypt, Fiji, India, Indonesia, Kenya, Laos PDR, Malaysia, Papua New Guinea, China and Viet Nam, and they have been held in identified hatcheries in order to maintain their genetic purity and specific quality of the stock. In some of these countries, efforts have been made to improve these stocks further through the selective breeding process. Bangladesh is reported to have evolved an improved strain of tilapia which has been named as "super gift tilapia". The selective breeding process has helped to improve the growth by 12–17 percent per generation.

In order to ensure continuity of the genetic improvement programme and the sustainability of the activity, WorldFish Center has transferred the project fish collections to the newly established GIFT Foundation Inc., which is a non-stock, non-profit corporation established by the institutional partners involved in the project. The foundation has made an effort to distribute GIFT tilapia to private hatcheries on a licensing basis. However, as the private hatcheries were reluctant to enter into an agreement involving legal documentation procedures, after two years of experience, agreement was made with a Norwegian private company, GenoMar ASA, to ensure wider distribution of the genetically improved stock through their established management structures.

The procedure demonstrated by this project in establishing responsible management of a certain genetic stock has contributed in many ways to the further improvement of new strains through country-specific breeding programmes. Such a success has been largely possible due to the well-planned scientific programme, which was focussed on dissemination of the strain together with capacity building of the national staff charged with continuing the required breeding activities beyond the project phase. This project has contributed not only to food security but also to poverty alleviation, thanks to the high demand for the product in the global market (Acosta, Sevilleja and Gupta, 2006; Acosta and Gupta, 2010).

It is also important to note that the project envisaged building the capacities of various governments and institutions during the implementation period. This activity was introduced in the programme in order to support the original objectives of improving the performance of tilapia through a selective breeding process. In order to continue this capacity-building process, as well as sharing of information, the International Network on Genetics in Aquaculture (INGA) has been established, based in the WorldFish Center headquarters. Periodic meetings of INGA to share information and ideas through mutual consultation processes have brought benefits to the countries and individuals participating in the programme.

This project has contributed immensely, not only in providing an improved strain of tilapia, but also by stimulating research in the application of selective breeding methodologies to other species such as labeo roho and silver barb and to other strains of tilapia. The major lesson learnt through this project is that partnership research programmes involving developing and developed countries can bring great benefits to the people through the application of good science. Further, partnerships between research institutions and the private sector can stimulate rapid development and dissemination of technology. The project has also proven that investment in human resource development can bring sustainable benefits for the improvement of the aquaculture sector. The impact of this improved strain of tilapia has contributed to the dramatic increase in production in many countries of Asia.

Dissemination of sex-reversed tilapia technology developed by the Asian Institute of Technology

The Asian Institute of Technology (AIT) developed the technique of sex reversal for the production of all male tilapia production during the 1980s. For the dissemination of the technology, the institute established several partnerships with private hatcheries and also helped in spreading the technology of production of monosex tilapia by using 17-alpha methyl testosterone. The technology involves the rearing of quality broodstock and egg production with the appropriate male to female sex ratio. Fertilized eggs collected from the mouths of female tilapias are incubated with continuous flow of water. The hatched larvae are fed with artificial feed incorporated with the hormone for about 30 days. These sex-reversed all-male tilapia grow faster, and this is also a feasible way of avoiding the constraint of early maturation.

AIT's training unit undertook several initiatives to organize training and technology transfer to rural fish farmers all around the country on the production of monosex tilapia and their culture in confined environments. As a result, the technology spread very rapidly in Thailand, where it has contributed to a major revolution in tilapia culture.

Well-planned research programmes coupled with a strong outreach programme made a major impact by addressing several of the problems encountered in the promotion of the technology. In addition, as part of the outreach programme, several training projects were organized on breeding and farming systems for tilapia, and these attracted the interest of various countries and agencies which have taken the opportunity to train their own personnel. In addition, a master's degree (M.Sc.) programme in aquaculture developed by AIT helped in producing well-trained manpower to address major problems faced at the field level in different countries. As a result of this sustained effort, tilapia breeding and sex-reversal technology has been spread to several countries in Asia with very good results, particularly in Bangladesh, Viet Nam, China and Malaysia.

Periodic short-term training courses organized by AIT on tilapia seed production and training technology have facilitated the development of manpower with the required skills and knowledge, not only in Asia but also in Africa and Latin America. The hands-on training, coupled with successful hatchery operations within the institute and with field training and research involving private hatcheries in Thailand have helped trainees to see the practical results of the programme and thus helped build their confidence in the technology. Since AIT has a successful M.Sc. programme in aquaculture that is mainly focused on Asia, it has been able to attract a good number of technicians from different Asian countries; such trained human resources have also facilitated the spread of the technology (Bhujel, 2008).

The lessons learnt from the AIT experience clearly demonstrate that well-founded education combined with practical training and supported by active research programmes could help in the spread of technology. Quality human resource development is the key for spreading appropriate technology.

Integrated Fish Farming Training Centre, Wuxi, China

China is not only the leader in aquaculture production, but has also led in disseminating knowledge and technology on aquaculture and fishery management during the last three decades. The Freshwater Fisheries Research Center (FFRC) in Wuxi has been organizing training for people from various countries for the past 30 years. The course and seminars were designed mainly to build the capacity of people from developing countries in aquaculture and fishery management. The training programme on integrated fish farming, which started as an FAO-United Nations Development Programme (UNDP) supported activity, focused on the integration of fish with other animals and farming systems, has attracted interest from many countries involved in aquaculture. In 1992, the training programme was taken over by the Government of China and is run as an international programme supported with full funding by the government. The training programmes have now been diversified into both aquaculture and fishery management. To date, the center has attracted participants from 100 countries and more than 1 400 persons have been trained. While most participants were men (81 percent), the number of women trainees has clearly increased in recent years. NACA has been coordinating the selection of trainees from member countries and facilitated the travel and training during the early years. The hands-on training gives an opportunity for the participants to gain experience in aquaculture technologies such as pond construction, seed production, feed management, disease prevention, etc. The integration of fish with animals such as pigs, ducks and cattle and with plants such as paddy and mulberry has demonstrated sustainable models of resource utilization.

The Wuxi center was built with all the necessary facilities for training, research and extension activities, combined with good fish farms, hatcheries and successful integrated farming systems for field practices within the campus, as well as facilities close to the center that have made this programme highly successful (Anon., 2005; Bueno, 2005a,b). Alumni have made visible impacts in many countries by applying some of the good practices. The approach of China in spreading knowledge, even to the extent of covering all costs for participants from developing countries, is a noteworthy example for other countries to emulate.

The lesson learnt from this programme is that practical training on various aspects of fish seed production, integrated fish culture, feeding strategies and disease management, as well as sustainable and responsible approaches in natural resource management have enabled trainees to gain confidence in these activities and replicate them in their countries. Exchange on lessons and experiences on China's fishery and aquaculture development history would also help trainees and participants. Most importantly, trainings of this nature have helped participants to learn from each other, exchange experiences, ideas and technology, learning about the aquaculture practices prevalent in different regions of the world and the problems confronted in developing the culture systems. These trainings have helped to build strong linkages between trainees and the faculty of the FFRC and with the companies in the fishery industry. In addition, cultural linkages have been a major benefit.

Network of Aquaculture Centres in Asia-Pacific

The Network of Aquaculture Centres in Asia-Pacific (NACA), an intergovernmental institution created with the purpose of sharing information between countries in the Asia Pacific region, has proved to be one of the most successful experiments in the aquaculture world. In the past 25 years, NACA has taken up the role of bringing all its member countries to a regular platform to discuss the issues and develop strategies for aquaculture development through regional cooperation (Bueno, 2006a,b). Currently, there are 21 member countries and the organization is managed by representatives from all members. The NACA Governing Council is chaired by a member country representative on an annual rotation, providing all the countries equal opportunity. A Technical Advisory Committee comprised of experts nominated from each country provides the necessary technical support on training, research, exchange visits, planning and implementation.

NACA's many accomplishments include information dissemination, well-planned and targeted training programmes, field-based strategic research programmes that address common problems encountered by member countries, and influencing policies through educating the right people. NACA's efforts to focus attention on the problems caused by fish and shellfish diseases through a number of training and research initiatives is a major contribution to the region. NACA serves as a regional nodal organization and has been working closely with FAO and a number of other donors in a wide range of activities, projects and programmes. Attempts have been made to create similar regional platforms to promote aquaculture development in various parts of the world, including Central Asia, Africa and Latin America. The positive lesson learned is that professionally managed organizations such as NACA can attract funding for various activities and bring benefits to people. The presence of NACA has been extremely helpful, not only to exchange expertise, but also to address emergency situations, particularly when calamities such as floods or epidemic diseases occur, as in the case of Asia after the tsunami of 2004.

"Aquaculture Asia", a quarterly magazine published by NACA and made available for free Internet download, has helped in information dissemination in many ways. Several of the innovations and farmer practices documented in the magazine have stimulated aquaculture development in many countries. The Website, with free access and download of specific and aquaculture-related publications, has become a popular site within the aquaculture community. Over the last few years, NACA has increased its impact on the science of aquaculture, basing its development strategies on the findings of scientific investigations that are open to public scrutiny and peer review.

National Centre for Sustainable Aquaculture

The success accomplished through the NACA-MPEDA (Marine Products Export Development Authority) project in India has helped the creation of a new institution called the National Centre for Sustainable Aquaculture (NaCSA) by MPEDA (Padiyar *et.al.,* 2003; Umesh, et.al. 2010). The institution was created in 2007, and has already made great impact in terms of promoting best management practices (BMPs) through a cluster approach. The activity has been expanded to cover six of the coastal states involved in shrimp farming in the country. The institution has established several farmers' welfare societies and has encouraged farmers to initiate aquaculture through a group-collaborative approach. These farmers have also been linked to international buyers. Because of this direct linkage between the companies, the importing countries and the producers of the developing countries, they will be able to get higher market rates for the produce. So far, more than 750 societies involving 16 500 farmers have been established, and their produce will be sold directly to the SYSCO Corporation in the United States of America through an agreement to buy 10 000 tonnes of shrimp. The established group has helped to reduce disease incidence, increased productivity and quality, increased access to good-quality products, increased profit through reduced production costs, and improved market access through increased ability to meet market requirements such as organic certification, traceability and eco-friendly sustainable production. Revival of abandoned ponds, increased food security, improved livelihoods and empowerment of small-scale farmers to have a collective voice have been the significant outputs of this group approach. The institution that has been created has been able to make a great impact using contractual employees whose continuation is directly linked to their performance. This is the first experimentation that clearly reflects good success when an organization has well-defined programmes and performance assessments. NaCSA aims to reclaim most of the abandoned farms through organizing farmer groups and promoting aquaculture through the cluster approach. The lesson learnt is that shrimp can be grown with reduced disease problems provided sustainable BMPs are adopted through a cluster approach.

The implementation of BMPs through the cluster concept has provided benefits to the farmers, the environment and the local community. A summary of the project's impacts is given in Table 1.

There are many lessons to be learnt from the work of this project. Such lessons are not only useful in improving the processes with time but could have relevance and application to the development of small-scale practices. Examples include:

- Improved farm management practices can reduce environmental impacts, ensure food safety and improve farm profit. The "win-win" situation created by adoption of better management provides a strong incentive for positive change.
- Organization of small-scale aquaculture farmers brings about positive social and economic benefits to members. These benefits include:
  - Collective planning and shared responsibility help achieve better management of risks.
  - Cluster model of BMP implementation is developing into a self-propagating model (farmers believe farmers).
  - Farmer groups can have stronger negotiation power with the input suppliers and traders.
- The following points should be considered while organizing farmer groups:
  - Farmer groups comprise farmers with different needs, interests, skills and financial and technical capacity. A few common interests can hold them together in a group.

  - To secure the confidence of farmers, provision of technical services should be independent and without conflict of interest.
  - Investment in institutions (e.g. NaCSA) that are focused on small-scale farmers can facilitate formation of groups and adoption of BMPs.
- Revival of the shrimp sector is possible. Shrimp farming can be a source of sustainable livelihoods for small-scale farmers provided risks are managed through improved management and institution building.
- Experiences from India are widely applicable in other countries across the region.

By the end of 2012, NaCSA plans to organize 50 000 small-scale shrimp farmers into societies and help them sustain their livelihoods. It will help societies switch to sustainable energy resources for their routine farm operations and facilitate access to institutional finance and insurance. |By 2011, cluster certification is planned for about 100 societies and by 2013, all 2 000 societies should be certified. This will help the societies meet emerging market requirements and improve the market access for their produce. Empowered farmers can influence policy-making in their favour.

TABLE 1
Summary of the positive impacts of the National Centre for Sustainable Aquaculture

Risks	Positive impact	Remarks
Disease	– Reduced disease incidence	– 27% decrease in disease prevalence in BMP ponds compared to non-BMP ponds.
Food safety	– Reduced chemical & no antibiotic use	– All preharvest shrimp samples from society ponds tested negative for presence of antibiotics. – Complete traceability of the product.
Improving supply chain & market access	– Increased opportunity for market access	– Middlemen/agents eliminated at all levels of production, finance and marketing. – Plans are in progress to market society-produced shrimp to Sysco Corporation, USA for better price.
Financial	– Improved profits – Opportunity for bank credit access	– By reducing the cost of production, profits have been increased. Non-BMP ponds got INR39 (USD0.8) for every INR1 000 (USD20) spent, whereas BMP ponds got INR128 (USD2.6) for the same amount of investment during the 2009 harvest season.
Social	– Democratic & transparent societies – Increased communication – Sharing of costs – Development of local leadership	– Democratically organized farmer groups. – Regular information sharing among farmers. – Cooperation in selecting, testing and buying quality seed and other inputs. – Farmers share cost to build common infrastructure (electricity, laboratories, auction hall, etc.) – Organization of farmers into societies helps to develop local leadership. The most successful farmer societies have strong leaders who have vision and commitment, which is very important for society management and success.
Environmental	– Lower stocking densities – Reduced pollution – Increased environmental awareness	– Stocking density of society shrimp ponds (<10 shrimp/m^2) is far below that used in other countries. – Maximized efficient water use by reduced water exchange and minimized discharges. – Five societies have adopted organic aquaculture practices. – Abandoned shrimp ponds being revived.

Establishment of fish farmers' networks

Fish seed producers' networks, established largely in the private sector in many Asian countries, have contributed to aquaculture development in many ways and in many regions. Successful examples of these networks are seen in Bangladesh, India, Viet Nam, Lao PDR, Thailand and Cambodia (Little, Nietes-Satapornvanit and Barman, 2007). These networks assist in the effective distribution of proven and certified quality seed with a fixed price to areas that are generally not accessed by government extension workers or public hatcheries. The networks operate in different ways in different countries, based on the circumstances, labour availability, ease of transportation, etc. In Bangladesh, while the nursing operation is carried out by groups of farmers, a number of poor people are engaged in seed distribution. These seed distributors have also been used as message delivery agents, in view of their ability to reach various locations.

While the seed network system exists almost in a similar way in West Bengal, India, in Southeast Asia, these networks have proved to be successful in meeting the seed requirements of farmers by employing various communication mechanisms. In Thailand, with tilapia being a prominent culture species, establishment of these networks in northeastern areas have stimulated a good growth of the aquaculture sector.

Cambodia, which is emerging as a quite important country and organize within the aquaculture sector, also has a long history of seed producers' networks. The success in aquaculture has been largely due to seed production facilities being established in different parts of the country and the establishment of networks to address various issues related to seed production and distribution. As the number of seed producers has increased, with a view to create a platform for the exchange of information and develop strategies to ensure quality seed production, fish seed networks have been established in four provinces. The network members meet once a month to discuss various issues related to technology, management and marketing of fish seed, including fixation of prices for the fish seed to prevent undue competition. Annually, network members are brought together to present their experiences and discuss the strategies that are needed to ensure quality seed supply to farmers. These annual meetings also provide an opportunity for the members to present their problems collectively to government authorities. With the participation of various NGOs, donors and provincial authorities in such meetings, many of the management issues are resolved and plans are made to enable the farmers to continue their activities. The network has proved to be an effective platform for dissemination of information.

Productive linkages between farmers and scientists

There are several examples from Uganda of successful synergic approaches between farmers and researchers from both public agencies and NGOs. For instance, the National Agriculture Research System, where public research for aquaculture falls explicitly, calls for on-farm or field-based research as the ideal research and outreach strategy. During recent years, these partnerships have promoted the use of three new indigenous fish species for aquaculture purposes and the improvement of fish feed, hatchery operations and management, and the handling, processing and marketing of farmed fish. Partnerships with farmers are a rule, not an exception for the Ugandan Government, with farmers involved right from deciding on the kind of research that has to be undertaken through the entire research process and programme.

A quite didactic example from Mexico is the collaborative approach between farmers and scientists from the Northwest Biological Research Center, in an attempt to bridge the innovation gap through BioHelis, its innovation and technology park. Over the last 20 years, this interaction has allowed for significant advances in aquaculture production. Based on more than 60 research papers and 20 theses relating to critical aspects of reproduction, nutrition and production, technology development has allowed commercial producers to obtain more than four times the number of juveniles per square meter in greenhouse systems without water exchange, and at cost reduction of up to 14 percent when compared with traditional techniques. On the other hand, intensive commercial grow out with 0 percent water exchange and controlled aeration allows for an increase of up to 73 percent on reported production rates, with a reduction of more than 20 percent in production costs. The technology reduces energy consumption, improves feed conversion rates, optimizes the use of water and significantly reduces the cost of production.

Examples of linkages between on-farm experiences in partnership with research institutions and public bodies in Mexico

After the appearance of white spot disease (WSD), the two main producers in Mexico, the states of Sinaloa and Sonora, (with a production of 80 to 90 percent of the national yield) have had varied performance. Sinaloa was the production leader for many years, and in the early 1990s it was responsible for 80 percent of all production, but now production has dropped to 30 percent. Sonora has displayed quite the opposite pattern: during the early 1990s it was responsible for 15 percent of the production volume, but in the last four years, it has generated 60 percent of the national shrimp production.

We will now see the process lived by the Sonoran farmers in their search for a healthy and pathogen-free environment. In 2001, the states of Sinaloa and Sonora began a new season of uncertainty: WSD appeared in different regions, sometimes devastating an entire zone, yet the neighbouring area remained safe. In order to control the situation, a group of farmers –under the banner of the Asociación de Acuicultores Privados del Estado de Sonora A.C. – developed a plan focused on aquaculture health. Research began by examining other similar fields such as vegetable, porcine and avian health, and the necessary paperwork was done before state and federal agencies, as well as before the shrimp farmer's guild. As a result, on July 2002, the Comité de Sanidad Acuícola del Estado de Sonora (COSAES, the Aquaculture Health Committee of the State of Sonora) was created, and it was composed mainly of shrimp farmers. It was the first entity of its kind in Mexico, and some time later the other states created their own committees. These entities collaborate with governmental agencies such as the Comisión Nacional de Acuicultura y Pesca (CONAPESCA, the Nacional Commission for Fisheries and Aquaculture) and the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA, the National Quality Service for Healthy and Innocuous Agrifoods), and its main objective is to promote the use of good sanitary practices in the management of shrimp farms.

Once COSAES was constituted, it proceeded to elaborate a sanitary protocol for the 2003 cycle under which all farms and hatcheries in the state would operate. Stocking and harvest permits – documents that are issued by this committee – were only given to farms that followed these sanitation protocols. By 2003, 95 percent of all farmers obtained their stocking and harvest permits. These positive results improved every year, and Sonora went from producing 18 000 tonnes of farm-raised shrimp in 2002 (the year of COSAES' inception) to 68 000 tonnes (higher than the national fisheries yield) in 2007, and this in a scenario of diminishing yields in all other regions.

Nonetheless, without the existence of a law or norm issued by either the state or federal governments to fully support the agreements settled under COSAES, there was never 100 percent compliance to its protocols, and thus emerges the necessity to elaborate an aquaculture law that will grant it the powers needed to exert full compliance and apply sanctions and fines to offenders. So the next step was the generation of a State of Sonora Aquaculture Law, issued in December 2005, and from this moment, all producers fully complied with the protocols. It is important to state that the juridicial actions undertaken by Sonora were responsible for the creation of the Ley General de Pesca y Acuacultura Sustentables (the Sustainable Fisheries and Aquaculture Law), published on 24 August 2007. In order to conform to the federal law, the State of Sonora's law was modified and the Fisheries and Aquaculture Law of the State of Sonora was issued on 28 August 2008. Nowadays, Sonora is the only state with such a law, and this might be the main difference with the actions implemented in Sinaloa.

Use of information and communications technology (ICT) in the information dissemination process

Among the many different types of communication systems, electronic communication tools and mechanisms are extremely fast, feasible, easily accessible and affordable. Although there are still difficulties in many developing economies to access the Internet, the situation is improving rapidly with the participation of the private sector and specific government policy initiatives to ensure adequate communication linkages to remote areas.

Tilapia@yahoogroups.com

One of the successful networks is the tilapia group (tilapia@yahoogroups.com). The group started in 1999, has successfully completed 12 years and now has a membership exceeding 3 000 people. This group, started by Mr Tom Fresse of Aquasol Inc in Hawaii, is helping people from different countries and with different backgrounds to register as members and obtain the necessary information. It was started based on the fact that there are thousands of tilapia farmers all over the world who would benefit from such a global exchange of information specifically related to tilapia. As the mailing list comprises of all types of farmers operating small to large farms that are focused on domestic and commercial production, researchers, development professionals, etc., it not only provides a platform to share diverse experiences but also a very global overview of the reality of the sector. The group has been managed by Tom Fresse, with no cost involved, excepting his time and resources. On a daily basis, he spends about 15 minutes on average managing the list, but occasionally it can be several hours. Most of his time is spent on sending invitations and managing and editing the posts. There have been some problems encountered regarding language barriers, commercial posts, e-mail prospecting by people not interested in tilapia, flaming, personal messages, member removal requests and poor quality posts. To overcome these problems, mail moderation has been started. No attachments are allowed, but provision has been made to upload files where people can access them and download the information.

Although, moderation is viewed differently by different people, without moderation, maintaining such a large group with diverse interests would not be possible. Furthermore, unnecessary and unrelated mail delivery can contribute to loss of members, as the increased mail can cause loss of time. Moderation has proved to be effective in improving quality and regulate mail traffic. Many professionals have been invited to join the group. Their advice and unselfish service have helped maintain the quality. It is really the quality of the posts that makes the difference. Based on the experience of 12 years, Tom's advice to others wishing to start a group is to go for it! It's not hard and once it is set up and running with a reasonable membership count in place, the group will quickly have word-of-mouth positive feedback, and you will see membership rise with little or no effort. One of the most fascinating experiences about the list is learning how different countries operate their tilapia farming industries; such a global platform provides opportunity to learn from each other's experience.

Sustainable Aquaculture Research Networks for Sub Saharan Africa (SARNISSA)

SARNISSA is a network created to improve access to information through individuals in sub- Saharan Africa (SSA) and beyond. This project was upported by the European Union, in collaboration with institutions from Africa, Asia and Europe, and with the Institute of Aquaculture, University of Stirling as the lead center. This project, with more than three years of existence, already has large number very active members from all parts of the world, majority representing all major institutions and organizations in Africa. Effective dissemination of information using both English and French is much appreciated by all the members. The principle objective of SARNISSA is to strengthen the capacity of African researchers and development professionals by enabling them to have access to information. In addition to the e-mail group, there is also a Website which serves as a repository for various information. With the support ending from European Union, efforts are on to find ways to sustain the activities and members themselves have been actively involved in finding ways to continue this platform.

Other successful methods

In countries like Thailand, print media are often preferred by farmers, and much of the extension material on various cultured species is produced by the Thai Department of Fisheries as hard copy. In China, television channels dedicated to agricultural activities appear to be a popular means for farmers to receive new information. In Bangladesh, folk art is used as a medium to convey important messages. Providing information to farmers in their preferred manner is essential to having a maximum impact.

Emerging issues

Factors that ignite farmers' innovations

Interaction between science, technology and production is necessary for innovation in commercial and small-scale aquaculture. Production problems require specific technology developments that depend on basic and applied knowledge generation. Where there is an effective linkage between the institutions that generate new knowledge and the farmers using such knowledge, the technologies evolved will be further refined to best suit the farmers' specific needs. Even in the absence of such an effective linkage, innovative farmers of commercial magnitude have found their way to the technologies prevalent in different parts of the world and have evolved commercially viable systems. In most cases, they have followed an innovative approach to adapt validated fish farming strategies and technologies to their own environmental, socio-economic, cultural and political contexts.

Farmer innovation is encouraged by the need to maintain viable production. This is generally associated with economic returns. In some instances, social and environmental sustainability are also drivers for innovation. Social needs, such as food security, better income generation and the cultural history of fish in livelihoods have defined innovative pathways in aquaculture development; environmental needs, such as the preservation or restoration of local species, have also been drivers of innovation.

In the case of small-scale aquaculture, one of the main drivers for farmer innovation has been the increasing demand for aquaculture products. With the declining catches from rivers and lakes, the price of fish has more than doubled in the last five years, thus providing impetus for aquaculture development. A profit-oriented approach has motivated farmers to increase farm productivity to meet and ensure consistency of supply. In continents other than Asia, this has resulted in not only adoption of Asian technology, but in many instances, the hiring of Asian technicians to guide aquaculture operations.

Critical to the promotion of farmer innovation in small-scale aquaculture, technical support and assistance from development agencies like FAO, the WorldFish Center, the World Food Programme (WFP), and other regional organizations like NACA and several NGOs have been forthcoming. However, success has come only with those interventions that have engaged and facilitated the farmers to improve on their own rather than by replacing government in direct intervention by providing free services and inputs (hand-outs). These interventions have been especially useful in supporting farmers to acquire the necessary technologies from elsewhere.

Main factors to consider

It should be noted that most of the factors listed below could be considered either as favouring or limiting factors for farmers' innovations; the positive or negative impacts depend on the context.

Environmental factors

Water availability and quality, land availability and soil quality, temperature, pluviometry and freshwater species biodiversity have helped innovative fish farmers to adapt the existing farming systems to a specific environmental context.

Socio-economic factors

There are many socio-economic factors that impact on farmers' innovative approaches, such as fish demand, marketability and market structure, public general infrastructures, existing traditional knowledge and technologies, access to inputs, information, extension services and materials. One of the most limiting factors for fish culture establishment and development in remote rural areas is the access to inputs (e.g. fish seed and feed) and markets. Lack of appropriate inputs has generated crucial innovative approaches all over the world. Another key factor pushing farmers to innovate is the demand for fish products in local markets. Limitations in the form of lack of traditional knowledge and aquaculture background in some rural areas are also factors affecting innovation, pushing farmers to adapt validated culture systems from other regions to suit their own local conditions. Lack of access to cash flow and information (through proper extension services and materials) are two other factors that generate innovations in order to improve production efficiency using available resources.

Political factors

Many political factors can be considered as both favouring and limiting factors for fish farmers' innovations, depending on the context. For instance, lack of an appropriate legal framework promoting development and expansion of aquaculture could push farmers to innovate using available resources to meet market demands, but just to a certain level; lack of adequate policies also limits the future expansion of the sector in a long-term perspective. In some isolated rural areas, there is a high demand for fish products; however, without specific support from the government (e.g. access to credits, technical knowledge), farmers are pushed to create, adapt and innovate using available resources. Finally, inadequate basic infrastructure and geographical isolation have also generated innovations and adaptations in many regions.

Factors that hamper farmers' innovations

Several factors hamper innovation. Lack of information on the biology and aquaculture techniques required is a contributing factor. At the commercial level, however, farmers frequently indicate that economic constraints limit in-house development or appropriation of knowledge-based technology. Although science and technology policies are evolving, funding for innovation is still limited.

The socio-economic context of a certain region is crucial for innovation, as it could limit what the farmers can use and adapt to aquaculture. For example, lack of simple mechanical tools and equipment makes many farmers' innovations untenable and impractical. Inability to use the new ICT technologies greatly inhibits farmers and removes them from the loop of global aquaculture information and technology. Among the major limitations for farmers to innovate is a lack of traditional knowledge on aquaculture and skilled and experienced extension services.

Another major limitation that has hindered faster progress of aquaculture is the lack of high-quality inputs such as feed and seed. With regard to feed availability, in most cases the private sector is reluctant to invest in the feed industry because of lack of a critical mass of farmers to generate effective demand, yet there cannot be a critical mass of farmers without quality feed.

The cost of capital is another big limitation: if it is available, normally it is with high interest. This greatly affects realization of potentially important ideas and innovations. However, a few governments in developing countries are making deliberate interventions to reduce the cost of capital by assisting the banks to manage some of the risks associated with agriculture investments.

As mentioned earlier, most of the factors that ignite farmers' innovations could also be considered as limiting factors as well. These include:

- inadequate extension services and lack of access to technical knowledge, information and other didactic materials;

– lack of capitalization of validated technologies;
– inappropriate technology transfer methodologies from technicians to farmers and from farmer to farmer;
– inefficient discussion platforms among stakeholders involved in aquaculture (e.g. technicians, experts, scientific community, politicians, extension workers, farmers, and local and international NGOs); and
– lack of communication and exchange of ideas and knowledge among fish farmers (i.e. through the establishment of fish farmers' networks or other farmer to farmer technology transfer mechanisms).

We should also consider as relevant limiting factors:
– inappropriate or not updated regulatory frameworks or specific policies for the promotion, development and expansion of small-scale aquaculture;
– lack of linkage between the public and private sectors;
– inappropriate extension materials and extension programmes;
– isolation;
– inadequate basic infrastructure and services;
– poverty and low socio-economic situation, in general; and
– difficult access to credit and aquaculture-needed inputs.

Organizational and policy changes needed to promote farmers innovations

Policy change should focus on the following areas:
– providing access to the required natural resources (e.g. water, land, feed and seed) and inputs for aquaculture production;
– supporting farmers' technology transfer and innovations;
– promoting farmer training;
– enhancing the role of farmers' organizations;
– providing economic incentives for commercial feed production and distribution;
– developing and providing aquaculture extension services;
– developing appropriate regulatory policies and strategic development plans to promote healthy development of aquaculture; and
– creating a policy environment that promotes good aquaculture practices and best management strategies.

In the emerging era, public and private-sector partnerships can stimulate healthy development. Such partnerships can be best directed to promote and capitalize the farmers' innovations and validate indigenous knowledge. To accomplish this, large-scale public and private investment in aquaculture research and development should take place.

Globally, several countries have initiated programmes to document indigenous knowledge, validate it scientifically and undertake further research wherever necessary and disseminate such information for the greater benefit of society at large. In China, the Chinese Historical Fisheries Research Division has attempted to document the historical developments in aquaculture. In India, The National Innovation Foundation, created by the Government of India, reviews indigenous knowledge and practices regularly, documents them and scales up such knowledge based on the potential for production and commercialization by ensuring benefits to original inventors. The government has made a huge investment to promote innovations at all levels, including the farming community, to harness the potential innovative capacity of the billions of people and disseminate such innovations by ensuring that all the ethical principles are followed with regard to intellectual property rights. Annual exhibitions organized by the National Innovation Foundation of India attract large numbers of entries (generally several thousands) each year.

In the agriculture sector, the Indian Council of Agricultural Research (ICAR) undertook a major study throughout the country to document all the traditional knowledge prevalent in agriculture and validate it through scientific investigation. However, such indigenous knowledge-based information was scant and currently, the Central Institute of Fisheries Education has undertaken a project to document all such indigenous knowledge. The number of entries received in aquaculture is reported to be small, while in the case of fishing and fish processing, many examples have been received from different parts of the country.

On innovation, one of India's widely read newspapers, “The Hindu”, has carried a story on farmers' innovation in its Thursday issue every week for the past ten years (.Prabhu, 2000). This event has helped to create greater awareness of the positive role played by farmers' innovation in bringing innovation to the attention of the general public. Most of the agricultural universities in India also have progressive farmers on their boards of management, at the highest level, with a view to drive universities' policies and programmes to be farmer friendly. The University of Agricultural Sciences, Dharwad in Karnataka, India conferred an honorary D.Sc. to a farmer who has made several innovations in agricultural crops cultivation (Prabhu, 2009). However, there are several innovative farmers who believe that their innovations are copied by scientists and published as their own work, sometimes without even an acknowledgment. Innovations are being largely driven by common sense and curiosity, and it is necessary that the scientific community recognize the innovative potential of all people involved in the agrolivestock sector as innovators, since they face the challenges in their daily activities and invent new ways through curious observation. Evolving new ways to promote farmers as partners in scientific investigations would bring greater benefits. Farming-systems research and farmer participatory research that recognize the value of carrying out field work through the active participation of farmers and that also promote farmers as owners of innovations are not well known. With the increasing opportunities for information sharing globally, with least cost and greater speed, and through electronic platforms, there is a huge opportunity for various organizations, including FAO, to document and capitalize on indigenous knowledge and farmers' innovations and to disseminate successful technology transfer strategies widely.

The way forward

FAO should encourage educational and research institutions involved in aquaculture to document the indigenous knowledge prevalent in their area of operation, validate them scientifically wherever possible, and make such information available to the global community through an electronic platform, with due consideration to protecting the indigenous knowledge and promoting innovations of farmers under intellectual property rights (IPR).

The rapid expansion of the aquaculture sector in Asia, particularly by the small-scale farmers, clearly demonstrates the innovative ability of the farmers in adapting the technologies to their farming conditions. Wherever such integration with existing farming systems has been possible, aquaculture has expanded phenomenally. It is essential to support the integration of aquaculture with the prevailing farming systems. Development without focus on sustainability would hinder aquaculture improvement. Hence, a careful balance on integration, considering health of the system and the consumers, should be promoted.

Policy support and good governance promote innovations and disseminate knowledge through active partnerships, contributing to the rapid expansion of aquaculture. However, restrictive policies have also hampered aquaculture development and as a result, large parts of the resources available to aquaculture remain unutilized.

Dissemination of information through well-planned scientific interventions has always been successful and has shown maximum impact on society and on the development of the sector. Sustainability should be the key issue when considering mechanisms to disseminate information. As the circumstances vary from location to location and context to context, success and sustainability are not assured, even for proven technologies. Hence, people should be encouraged to undertake adaptive approaches to use of the information provided. Free access to information will help the people to make well-informed decisions.

Priority actions

The following actions are recommended:

- Document indigenous technology and innovations prevalent in different countries, validate the technologies through scientist-farmer partnerships and scale up good practices to bring better benefits to people.
- Promote interaction between the scientific community, students and farmers at the field level.
- Promote research, outreach and extension systems in partnership with policy-makers, scientists and farmers to address field problems.

- Invite policy-makers to experience field realities with farmer innovators.
- Increase the role of farmers in research planning and implementation.
- Promote farmer to farmer exchange in all possible contexts and opportunities.
- Place emphasis on capacity-building skills with knowledge of extension staff.
- Disseminate documented examples of indigenous knowledge and innovations through new technologies and institutions, particularly through regional networks and their Websites.
- Encourage relevant stakeholders (including policy-makers) involved in aquaculture to incorporate farmers' innovation, traditional knowledge and technology transfer at a small scale, and to incorporate these concepts into their project proposals, feasibility studies, food production strategies, implementation plans and projects affecting local communities.

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