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Fish-farming: the new driver of the blue economy

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Brussels, July 2013

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Context

Millions of people around the world find a source of income and livelihood in the fisheries sector. The most recent estimates indicate that in 2010 there were 54.8 million people engaged in the primary sector of capture fisheries and aquaculture. Of these, an estimated 7 million people were occasional fishers and fish farmers (of whom 2.5 million in India, 1.4 million in China, 0.9 million in Myanmar, and 0.4 million each in Bangladesh and Indonesia). More than 87 percent of all people employed in the fisheries sector in 2010 were in Asia, followed by Africa (more than 7 percent), and Latin America and the Caribbean (3.6 percent). Approximately 16.6 million (about 30 percent of all people employed in the fisheries sector) were engaged in fish farming, and they were even more concentrated in Asia (97 percent), followed by Latin America and the Caribbean (1.5 percent), and Africa (about 1 percent).

The LDCs, mostly in sub-Saharan Africa and in Asia, and home to 20 percent of the world's population (1.4 billion people), remain very small in terms of their share of world aquaculture production (4.1 percent by quantity and 3.6 percent by value).

Aquaculture, otherwise known as fish farming, is the controlled cultivation of freshwater and saltwater animals or plants. The aquaculture sector overall is highly diverse and fragmented, ranging from smallholder ponds in Africa providing a few kilos of fish per year to international companies with annual turnover in excess of US$1 billion. While capture fisheries production remains stable, aquaculture production keeps on expanding and is set to remain one of the fastest-growing animal food-producing sectors and, in the next decade, total production from both capture and aquaculture will exceed that of beef, pork or poultry. Much of this development has occurred in Asia, which also has the greatest variety of cultured species and systems. Asia is also perceived as the 'home' of aquaculture, as aquaculture has a long history in several areas of the region and knowledge of traditional systems is most widespread.

Its systems can range from an intensive indoor system monitored with high-tech equipment through to the simplest production systems such as small family ponds in tropical countries. At the other end of the scale are high technology systems, such as the intensive indoor closed units used in North America for the rearing of striped bass or the sea cages used in Chile and Europe for growing salmon and bream.

With capture fisheries becoming increasingly unsustainable due to overfishing, aquaculture is expected to overtake capture fisheries in supplying the world's protein requirements in the future (FAO 2012). In the recent past, some developing countries in Asia and the Pacific (Myanmar and Papua New Guinea), sub-Saharan Africa (Nigeria, Uganda, Kenya, Zambia and Ghana) and South America (Ecuador, Peru and Brazil) have made rapid progress to become significant or major aquaculture producers in their regions.

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

However, the vital contributions from fisheries and aquaculture to global food security and economic growth remain constrained by an array of problems. These include poor governance, weak fisheries management regimes, conflicts over the use of natural resources, the persistent use of poor fishery and aquaculture practices, a failure to incorporate the priorities and rights of small-scale fishing communities, and injustices relating to gender discrimination and child labour. Over and above, the impacts of climate change are also posing threats to sustainable aquaculture development thus requiring focused implementation of mitigation and adaptation strategies.

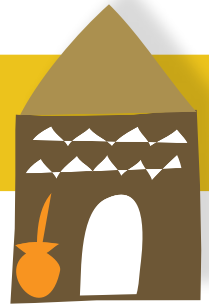
International frameworks in support of aquaculture

Since 2003, the FAO Committee on Fisheries (COFI) has recommended the development of international voluntary guidelines to complement the Code of Conduct for Responsible Fisheries (the Code) to promote good governance, participation and inclusiveness, social responsibility and solidarity. The 2011 FAO Technical Guidelines on Aquaculture Certification constitute an additional important tool for good governance of the sector. By setting minimum substantive criteria for developing

aquaculture certification standards, these guidelines provide direction for the development, organization and implementation of credible aquaculture certification schemes towards orderly and sustainable development of the sector.[1] Regional fishery bodies (RFBs) are the primary organizational mechanism through which States work together to ensure the long-term sustainability of shared fishery resources. The term RFB also embraces regional fisheries management organizations (RFMOs), which have the competence to establish binding conservation and management measures. Several countries have adequate national aquaculture development policies, strategies, plans and laws, and use "best management practices" and manuals on farming techniques that have been promoted by industry organizations and development agencies.

The FAO Technical Guidelines on Aquaculture certification

In 2011 FAO developed in cooperation with the Network of Aquaculture Centers in Asia-Pacific (NACA) guidelines for the development, organization and implementation of credible aquaculture certification schemes. The guidelines specify how credible aquaculture certification scheme consist in three main components: standards, accreditation and certification. Standard setting process are meant to develop and review certification standards. Accreditation systems needed to provide formal recognition to a qualified body to carry out certification. Additionally certification body, required to verify compliance with certification standards. The guidelines cover four range of issues which are considered as relevant for certification In aquaculture, and an aquaculture certification scheme may address one or all of these issues: i) Animal health and welfare; ii) Food safety and quality; iii) Environmental integrity; iv) Social responsibility. For each of the issues, minimum substantive criteria are specified. For example, regarding social responsibility, it is underlined how workers should be treated responsibly and in accordance with national labor rules and, where appropriate, ILO conventions should be applied. In the criteria it is also specified how child labor should not be used in a manner inconsistent with ILO conventions and international standards. (FAO, 2011)[2]



2. Overview of the significance of the aquaculture sector

2.1 Aquaculture production systems

Aquaculture is characterized by a great variety of systems and environments. Below is presented a short description of them.[3]

Freshwater ponds and tanks

In 2008, freshwaters was the source of 60 per cent of the world aquaculture production in 2008 (56% by value), despite it only constituting 3 per cent of the planet's water, and only 0.3 per cent is of surface water. In this system, 65.9 per cent were carp and other cyprinids which are mostly cultured in ponds using semi-intensive methods. Salmonid farming (mainly rainbow trout in freshwater) constituted only 1.5 per cent, typically using ponds, concrete raceways and other types of tank that require higher throughputs of water to maintain a good water quality.

Freshwater cages

Cage-based aquaculture in both freshwater lakes and rivers has flourished in many countries, although some are now regulating use due to concerns over environmental impacts. Globally, Asia and especially China has the greatest freshwater aquaculture production in relation to land area, although some European and African countries are also significant. The Americas in particular are notable for relatively low freshwater aquaculture production per unit area.

Coastal ponds and tanks

Coastal ponds and lagoons and have been exploited in simple ways for fish, mollusc, crustacean and seaweed production for centuries. However, production has been expanded and intensified over the past 30 years. In warmer countries, the penaeid shrimps have tended to dominate brackish-water culture due to high-value, short production cycles and accessible technologies. Production has increased almost exponentially since the mid-1970s and now accounts for about 58 per cent of aquaculture production from brackish water (72% by value). In more temperate climates, brackish-water fish species are the main crop with varying degrees of intensification. Further expansion of brackish-water aquaculture is possible, although competition for land resources in some areas is likely to limit developments of the kind seen in some Asian countries. Coastal aquaculture using onshore tanks has developed in some areas (e.g. South Korea, Spain, Iceland), usually where other types of aquaculture would not be possible.

Coastal cage farms

For marine fish species with mid to high-value, floating cages have proved the most cost-effective production system across a range of farm sizes and environments (as determined by conventional financial appraisal; Halwart et al. 2007). The open exchange of water through the nets replenishes oxygen and removes dissolved and solid wastes. Most rely on feeding either complete diets or, for some species, trash fish. Cage units can be sized and arranged flexibly to meet the needs of the farm. Expansion is straightforward by increasing cage volume or number of units. Larger cages, especially in more exposed locations, become difficult and costly to manage with manual labour, so a range of specialist service vessels and equipment has been developed, especially in the salmon sector, to overcome such constraints. Economies of scale supported by mechanization have helped to reduce production costs substantially.

Marine molluscs and aquatic plants

Oysters and mussels are mainly grown on structures built above the seabed - poles or racks on the shore, or ropes suspended from rafts or floating lines. Most of the commercially grown molluscs feed on microscopic algae floating in the water, so the farmer does not need to provide any feed.

The cultivation of marine molluscs (mainly bivalves) and seaweed using simple methods has a long history in many countries and has become widely established as a coastal livelihood activity involving high labour inputs. Since the 1990s, however, there has been significant upscaling of production and the introduction of specialized equipment allowing larger sites and greater labour efficiencies. Total output of mollusks from coastal waters in 2008 was 12.8 million tones valued at US$12.8 billion. A further 15.7 million tonnes of seaweeds were cultivated in coastal waters in 2008 valued at US$7.4 billion.

Production Intensity	Description
Extensive	Systems requiring large areas of earthen ponds or water area; primarily for species in the finfish, mollusk, seaweeds, and shrimps and prawns species groups. Extensive production relies on natural productivity, but in ponds it is often supplemented by locally available crop wastes and other material. Little or no processed feed is used.
Semi-intensive	Primarily freshwater but also some coastal earthen pond systems in which natural productivity is augmented with fertilizers and farm made or industrially produced feeds. The majority of Asian finfish aquaculture is produced in freshwater, semi-intensive earthen pond culture systems.
Intensive	Some highly productive pond systems (e.g., shrimp, striped catfish), finfish cage culture and some high value species, such as eels in China. Intensive systems are mostly supplied with complete industrially produced pellet feeds that meet all of the nutritional requirements of the culture species.

Source: Hall, S.J., A. Delaporte, M. J. Phillips, M. Beveridge and M. O'Keefe. 2011. Blue Frontiers: Managing the Environmental Costs of Aquaculture. The WorldFish Center, Penang, Malaysia.

2.1.1. Main farmed species

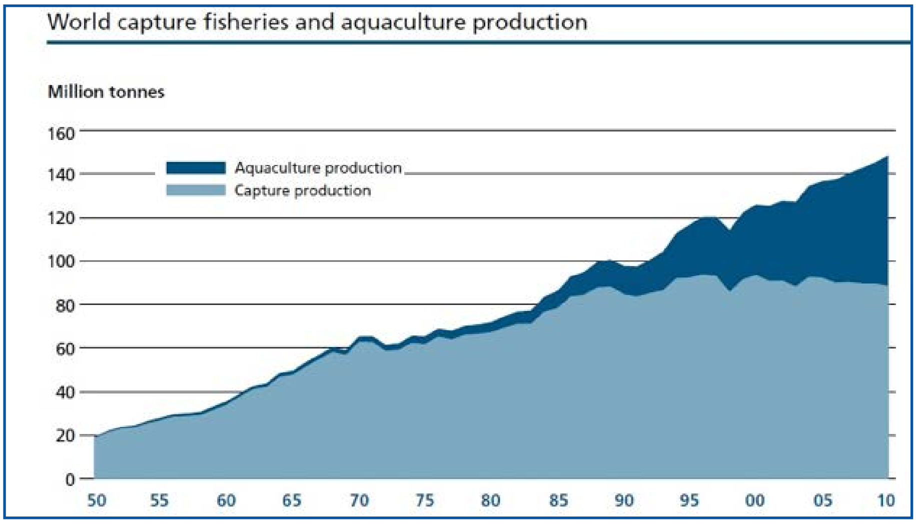
Aquaculture has pushed the demand for, and consumption of, species that have shifted from being primarily wild-caught to being primarily aquaculture-produced, with a decrease in their prices and a strong increase in their commercialization, such as for shrimps, salmon, bivalves, tilapia, catfish and *Pangasius.*[4] About 600 aquatic species are raised in captivity in about 190 countries for production in farming systems of varying input intensities and technological sophistication. These include hatcheries producing seeds for stocking to the wild, particularly in inland waters.[5] Farmed food fish include finfishes, crustaceans, molluscs, amphibians (frogs), aquatic reptiles (except crocodiles) and other aquatic animals (such as sea cucumbers, sea urchins, sea squirts and jellyfishes) that are indicated as fish throughout this document. Carp dominates production in both China and the rest of Asia. In contrast, for Europe and South America it is salmonids; African aquaculture production is almost exclusively of finfish, primarily tilapias. For Oceania, shrimps and prawns dominate while in North America production is more even across the species groups. The proportion of food fish supplied by aquaculture n 2008 was 47%. Supply from aquaculture is now dominant for seaweeds, carps and salmonids.[6]

Oceania is of relatively marginal importance in global aquaculture production. Production from this region consists mainly of marine molluscs (63.5 percent) and finfishes (31.9 percent), while crustaceans (3.7 percent, mostly marine shrimps) and other species (0.9 percent) constitute less than 5 percent of its total production. Marine bivalves accounted for about 95 percent of the total produced in the first half of 1980s but, reflecting the development of the finfish culture sector (especially Atlantic salmon in Australia and chinook salmon in New Zealand), they currently account for less than 65 percent of the region's total production. Freshwater aquaculture accounts for less than 5 percent of the region's production.[7]

2.2 Overview of production and trade in aquaculture globally

Capture fisheries and aquaculture supplied the world with about 148 million tonnes of fish in 2010 (with a total value of US$217.5 billion), of which about 128 million tonnes was utilized as food for people, and preliminary data for 2011 indicate increased production of 154 million tonnes, of which 131 million tonnes was destined as food. With sustained growth in fish production and improved distribution channels, world fish food supply has grown dramatically in the last five decades, with an average growth rate of 3.2 percent per year in the period 1961–2009, outpacing the increase of 1.7 percent per year in the world's population. World per capita food fish supply increased from an average of 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009, and preliminary estimates for 2010 point to a further increase in fish consumption to 18.6 kg.

Fish-farming: the new driver of the blue economy



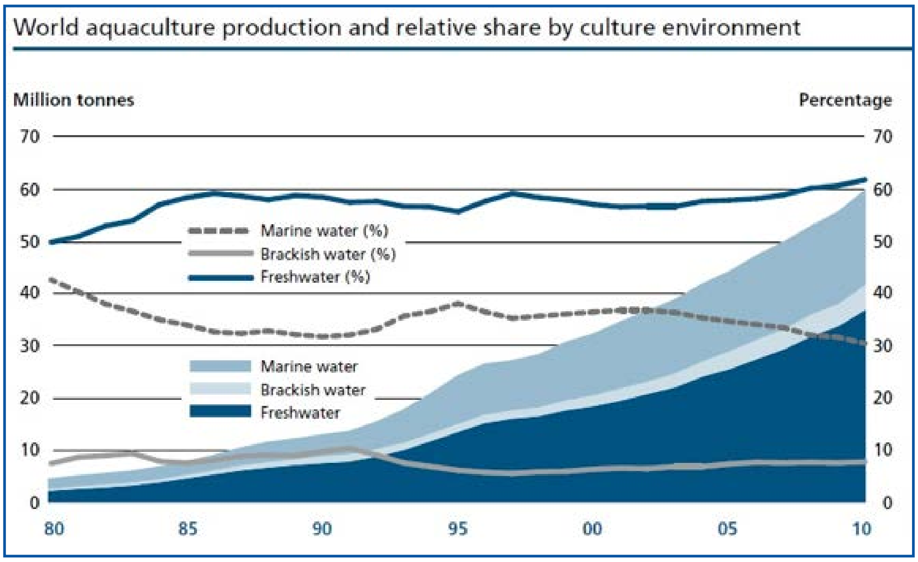
Source: FAO World Review of Fisheries and Aquaculture. 2012

Global aquaculture production has continued to grow in the new millennium, albeit more slowly than in the 1980s and 1990s. In the course of half a century or so, aquaculture has expanded from being almost negligible to fully comparable with capture production in terms of feeding people in the world. Aquaculture has also evolved in terms of technological innovation and adaptation to meet changing requirements. World aquaculture production attained another all-time high in 2010, at 60 million tonnes (excluding aquatic plants and non-food products), with an estimated total value of US$119 billion.

Aquaculture production using freshwater contributes 59.9 percent to world aquaculture production by quantity and 56.0 percent by value. Aquaculture using seawater (in the sea and also in ponds) accounts for 32.3 percent of world aquaculture production by quantity and 30.7 percent by value. Although brackishwater production represented only 7.7 percent of world production in 2008, it accounted for 13.3 percent of total value, reflecting the prominence of relatively high-valued crustaceans and finfishes cultured in brackishwater.

Although cultured crustaceans still account for less than half of the total crustacean global production, the culture production of penaeids (shrimps and prawns) in 2008 was 73.3 percent of the total production. The introduction of whiteleg shrimp (*Litopenaeus vannamei*) to Asia has given rise to a boom in the farming of this species in China, Thailand, Indonesia and Viet Nam in the last decade, resulting in an almost complete shift from the native giant tiger prawn (*Penaeus monodon*) to this introduced species in Southeast Asia.[8]

Data available at FAO show that, in terms of quantity, the percentage of production from freshwater rose from less than 50 percent before the 1980s to almost 62 percent in 2010, with the share of marine aquaculture production declining from more than 40 percent to just above 30 percent.



Source: WWF, 2013
http://wwf.panda.org/?unewsid=202534

2.3 The significance of aquaculture sector in ACP countries

Africa

Fish represents an important source of animal proteins for some 400 million Africans contributing essential proteins and micronutrients to their diets. Despite the high dependence on fish as a source of animal proteins, fish consumption in Sub-Saharan Africa is the world's lowest. The continent is projected to need an additional 1.6 million tons of fish per year by 2015 just to maintain current consumption. (WorldFish, 2009)[9]

Africa increased its contribution to global aquaculture production from 1.2 percent to 2.2 percent in the past ten years, albeit from a very low base. This was possible thanks to the contribution of rapid development in freshwater fish farming in Egypt and in Nigeria, Uganda, Zambia Ghana and Kenya. In 2010 Sub-Saharan Africa production amounted to 359, 790 tonnes representing 0.60 percent of global world production.

The biggest aquaculture producers in the region is Egypt which accounts for 71.38 percent of total production in Africa. In Sub-Saharan Africa, Nigeria is the major producer (15.57%) followed by Uganda (7.37 %) and Kenya (0.94%). Aquaculture production is dominated by finfishes (99,3 percent by volume), with only a small fraction from marine shrimps (0.5%) and marine mollusks. Despite some limited success the potential of bivalve production remains unexplored. In Sub-Saharan Africa, the carnivorous North Africa Catfish (*Clarias gariepinus*) has replaced Tilapia as the most produced fish in aquaculture since 2004. The progressive dominance of catfish species in aquaculture is particularly pronounced in Nigeria and Uganda. As the largest producer of catfish in Africa, Nigeria even imports catfish feeds from as far away as Northern Europe. (FAO, 2012)

Since 1980 different international donors, started investing in the aquaculture sector in Sub-Saharan Africa and the World Fish Center started projects of small-holder aquaculture in Cameroun, Ghana and Malawi. A central conclusion from these project is that the adoption of fish-farming by smaller producers can produced many benefits. Analysis of the development and dissemination of small-scale integrated aquaculture in Malawi suggests: total increase of farm productivity by 10%; per hectare farm income increased by 134%; total farm income increased by 61%; technical efficiency improved by 40%. Furthermore the number of smallholders practicing aquaculture in Malawi increased from 300 to 7000 over the past 25 years. Being farm productivity quite low, this data didn't impact national statistics but its impact on food security and of small households is significant. (Beveridge et al. 2010) [10]

The Sustainable Aquaculture Research Networks for Sub-Saharan Africa (SARNISSA), is a project

funded by EU to improve information flow and communication between main stakeholders in Sub-Saharan Africa. The consortium is formed by eight partners from Africa and Europe. The main aim of the project is to create a platform for sharing information among different stakeholders such as researchers, NGOs, commercial and market sector and government agencies. Through the further development of the Aquaculture Compendium the project aims to deliver a comprehensive interdisciplinary knowledge base required for Sub Saharan African aquaculture to develop in a sustainable way and so fulfill its potential to help increase farmers' incomes and increase food security.[11]

The case of UNIMA in Madagascar

Since 1990, the company UNIMA is operating in Madagascar to produce high quality shrimps. The French Ministry of Agriculture granted UNIMA, the 'Label rouge', a certification for high quality products. UNIMA, in partnership with the World Wildlife Fund (WWF), adopted environmentally sustainable practices and is investing in social development. UNIMA has opted for low density farming with 5 to 10 shrimps per square meter, instead of intensive farming with over 100 shrimps/m^2, a model that is common in many Asian countries. The farm is spread over 700 hectares of natural clay soil and produces over 2,500 tons of shrimp annually. Additionally UNIMA is supporting the reforestation of 45 hectares of formerly depleted land with fast growing tree species. Finally UNIMA is investing in the welfare of its employees and their communities through the construction of schools and a medical clinic.

Caribbean

The Caribbean region contributes less than one percent to the global aquaculture production and total aquaculture production in the region amounted to 36 871 tons in 2011. (FAO, 2012) The biggest producer in the region is Belize followed by Jamaica. Aquaculture in the Caribbean region is focused on the cultivation of non-native species such as Tilapia. The growth of aquaculture sector in the region is strongly influenced by lack of technical expertise, infrastructure, capital investment and human resources. (Lovatelli et. al. 2010).

In Belize, commercial aquaculture was established around 1980s and led to the rapid expansion of shrimp farming sector, with a total of 18 farms with and a production area of 2 790 hectares in 2005. As a result of disease events and major decline in global market prices in 2000 seven farms remain operational with a production area of 1 247 hectares. The main market destination for shrimp commodities is the Mexican market, followed by the United States of America and the Caribbean Community. Commercial aquaculture production in the country includes Tilapia farming as well as Cobia. Small scale aquaculture farming in Belize remains largely undocumented. It is mainly practiced in the form of backyard farming operations, with the cultivation of locally occurring cichlids species such as the bay snook (*Petenia splendida*), crana (*Cichlasoma uropthalmus*), mus-mus (Cichlasoma riedrichstali), tuba (Cichlasoma synspilum) as well as the exotic tilapia (Oreochromis niloticus). Most recently, farmers focused their interest in the farming of red-tilapia, in 2010.[12]

Guyana recently announced the put in place of national policy for inland fishing and aquaculture, that will follow the fisheries product regulation, the marine fishing regulation and the aquaculture regulation. Guyana in fact cannot access the markets of Trinidad et Tobaco due to poor quality standards of its aquaculture production in the region.

Pacific region

According to SPC, 2008 aquaculture sector employs in the Pacific region around 25,000 people, the major part of whom in Papua New Guinea.

If compared with fishing, aquaculture has a relative small commercial significance in the insular Pacific region with one important exception: black-peal farming which is confined to the French Polynesia. Elsewhere in the Pacific considerable development is needed before aquaculture can be considered economically sustainable. Shrimp (Penaeus spp.) farming has been a focus of commercial development in several islands over the past 30 years, with varying degrees of success; Tilapia (Oreochromis niloticus) aquaculture has entered the subsistence economy in some areas, and seaweed (Kappaphyces spp.) is considered a future commercial export prospect by the region. But the culture of other marine and freshwater species is, generally, still at the experimental or "backyard" stage. (Adams, 2000)[13]

Many of the large scale private sector pearl culture operations in Cook Islands, Fiji Islands and Marshall Islands appear to be successful (consistent production in the absence of subsidies). They appear to offer a positive model for emulation in the region. Substantial Tilapia and/or milkfish exists in American Samoa, Cook Islands, Fiji Islands, Guam, Kiribati, Nauru, Northern Mariana Islands, Palau, Samoa and Vanuatu with a total combined production in 2007 of 346 t. Significant shrimps culture is carried out in Fiji Islands, Guam, Northern Mariana Islands and Vanuatu. It appears to be highly dependent on demand from tourists and affluent residents. (Gillet, 2009)

Country	Farm-Gate Value of Production ($)
French Polynesia	123,708,046
New Caledonia	16,594,253
Cook Islands	2,235,294
Fiji Islands	1,749,375
Guam	948,000
Papua New Guinea	675,676
Vanuatu	303,846
Northern Mariana Islands	205,000
Marshall Islands	130,000
Federated States of Micronesia	80,000
Kiribati	75,630
Palau	50,000
Solomon Islands	40,654
Samoa	33,206
Tonga	18,317
Nauru	15,126
American Samoa	10,000
Tuvalu	0
Wallis and Futuna	0
Niue	0
Tokelau	0
Pitcairn Islands	0
Total	**146,872,423**

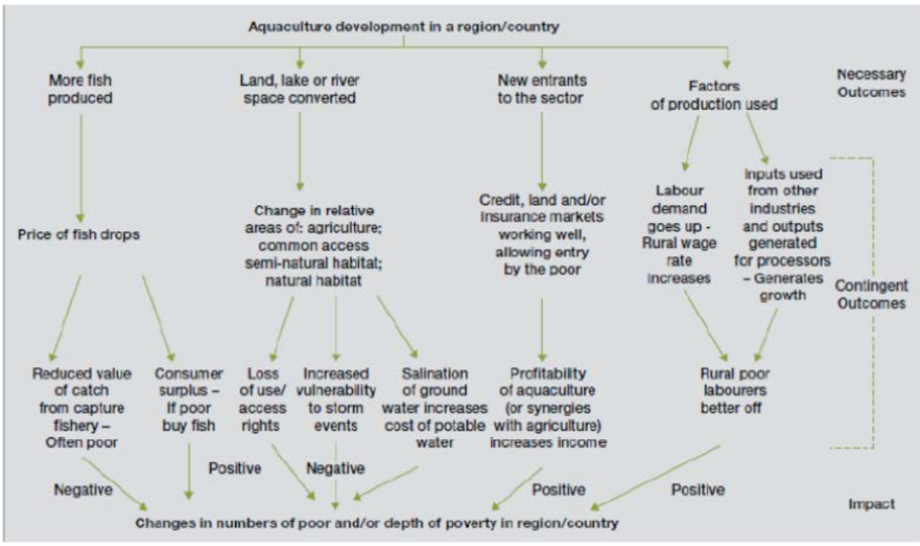
Concerning consumption, fish is extremely important for nutritional and diet purposes in the Pacific region. Bell et al. (2009)[14] estimated the existing pattern of fishing consumption in Pacific Islands and Countries territories (PICTs). According to his study fish consumption in many PICTs is remarkably high and many rural community in the Pacific depend heavily on fish. Subsistence fishing still provides the great majority of dietary animal protein in the region. Contribution of aquaculture to local food production is, in fact, not remarkable. In most countries where there is aquaculture production for local food supply it is tiny on a per capita basis, even in highest consuming countries, Guam and Nauru. Tilapia is by far the most important cultured commodity for local food.

3. Food and nutrition security and poverty reduction: potential benefits deriving from aquaculture development

Through innovations in technology and organization, intensification in operations, and diversification in products, species and culture systems, aquaculture continues growing towards a matured and global industry, accounting for half of the world seafood supply and with a large portion of its products traded across borders. While the sector is still mainly motivated by and promoted for its economic benefits, increasing attention has been paid to aquaculture's environmental and social responsibilities[15].

Over the past three decades, aquaculture has developed to become the fastest-growing food-producing sector in the world and as such it has achieved a reputation as a significant contributor to poverty alleviation, food security and income generation in many.[16]

Aquaculture and poverty reduction: potential impact pathways (Stevensen & Irz, 2009)



The development community considers aquaculture as an important domestic provider of much needed, high quality, animal protein, generally at prices affordable to the poorer segments of society. It is also seen as a valuable provider of employment, cash income and foreign exchange, with developing countries contributing over 90% of the total global production. When integrated carefully, aquaculture can also provide low risk entry points for rural development and has diverse applications in both inland and coastal areas. While export-oriented, industrial and commercial aquaculture practices can bring much needed foreign exchange, revenue and employment, more extensive forms of aquaculture benefit the livelihoods of the poor through improved food supply, reduced vulnerability to uncontrollable natural crashes in aquatic production, employment, and increased income.

Fisheries enhancements using appropriate culture techniques also provide important opportunities for resource-poor people to benefit from enhanced use of under-utilized, new or degraded resources. Such culture-based fisheries have considerable potential to increase fish supplies from both freshwater and marine fisheries, with concomitant income generation in rural inland and coastal communities.[17]

Aquaculture and nutrition security

Aquaculture can contribute to enhancing fishermen's nutritional security through different mechanisms. Fish produced by aquaculture can be either kept for household consumption or sold for cash income. Fish for household consumption contribute to dietary intake but the nutritional role varies with species . Fish sold for cash income contribute to purchasing sufficient staple foods, and can also be used for consumption or purchase of non-staple foods which directly improve dietary intake beyond energy intake.[18]

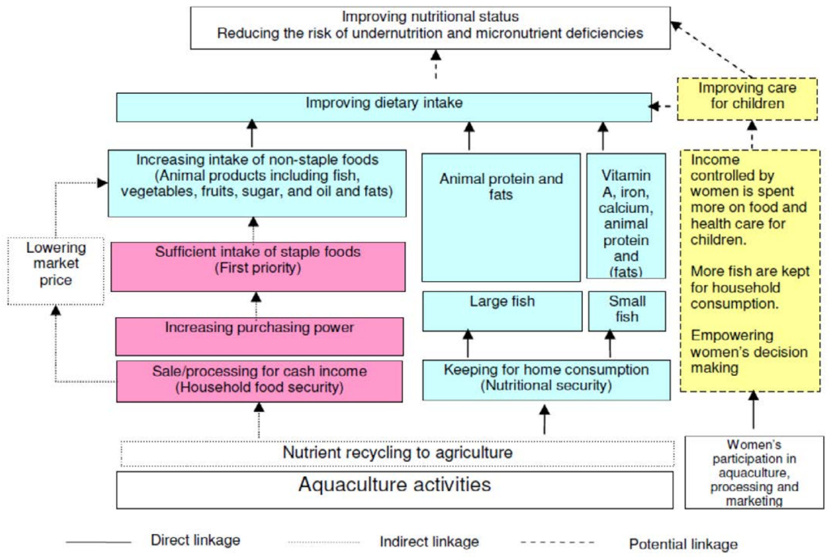


Figure 6: The pathways through which aquaculture can contribute to improving nutritional status

Aquaculture's links with fisheries and agriculture

Whilst demand for aquatic food products increases, production from capture fisheries at a global level is levelling off, and most of the main fishing areas have reached their maximum potential. Ocean fishery stocks are declining worldwide whilst fish and shellfish farming is undergoing rapid growth. The common perception of the contribution of aquaculture to the available fish supply is that aquaculture is an add-on to current ocean productivity. In particular it is believed that aquaculture production can compensate the shortfall in ocean harvests as ocean fisheries deteriorate, or that fish farming will restore wild populations by relieving pressures on capture fisheries.[19]

Fish production also constitutes an interesting opportunity to increase agricultural land productivity. Integrated aquaculture/agriculture (IAA) provides a means for rural systems to diversify and maximize output in developing countries. The culture method differs from mono-culture, which is often too risk intensive for resource-poor farmers. Integrated systems benefit from the synergies among the different components and they have diversity in production that results in a relative environmental soundness (Prein 2002). Integration can be categorized into: (i) polyculture (multiple species co-cultured; (ii) sequential (waste flows directed sequentially between culture units); (iii) temporal (replacement of species within the same holding site to benefit from waste generated by preceding species); and (iv) mangrove integration (using mangroves as biofilters) (Troell 2009).[20]

3.1 Empirical evidence of impacts

Pathways to food security and poverty

The global aggregate wealth generated from both aquaculture and fisheries in marine and freshwater environments is unquantified but, based on an estimate of US$ 225 to 240 billion for marine capture fisheries alone, is likely to be of the order of US$ 500 billion per year. The sector's economic output provides important contributions to poverty and food security through three main, interlinked pathways: (1) nutritional benefits from the consumption of fish; (2) income to those employed in the sector and multiplier and spillover effects in fishery-dependent regions; and (3) through generation of revenues from exports, taxation, license fees

and from payment for access to resources by foreign fleets or foreign investment in aquaculture.[21]

Trade impact on food security

Improved economic dynamism and purchasing power from trade will not result in welfare gains for vulnerable, food-insecure people unless the sources of vulnerability are also addressed. In the fisheries and aquaculture sectors, vulnerabilities arise from large inequities in relations of power between producers and buyers, or fishers and processing factory owners and exporters, or between men and women in fishing and farming communities.

For aquaculture, one of the few studies to quantify growth linkages relates to the shrimp farming industry in southern Honduras (Stanley, 2003). The study found that export-oriented commercial aquaculture exhibited low backward and strong forward linkages, but those were likely to be reduced with increased reliance on imported inputs as vertical integration and concerns for disease and quality management shaped the development trajectory of the industry (Stanley, 2003). The fiscal linkages were minor – mainly in the form of municipality taxes. Strengthening the local economic impact of larger-scale, capital intensive export-orientated production is a key area of challenge for policy, if ‘enclave development’ is to be avoided and the potential for such business to act as growth poles is to be maximized.[22] While aquaculture has greatly increased its economic contribution in the new millennium (FAO, 2009), it is still a less-established sector than fisheries or agriculture.[23]

Aquaculture development pathways: Impact on food security and poverty alleviation

Aquaculture growth has mostly taken place in Asia. The past fifteen years have seen the emergence of a vibrant small and medium enterprise (SME) sector, particularly in China, Vietnam, Thailand, Indonesia and the Philippines, which targets both domestic and international markets. Aquaculture for poverty reduction and food security is developing fast, but not always in ways promoted by many development agencies. Rather than being a means to secure nutritional gains and income directly for the poorest smallholder farmers, it is increasingly a means to increase domestic fish supply to low-income consumers, develop opportunities for employment, support local economic multipliers, and to generate revenue from trade. Impact assessment studies in Malawi, Bangladesh and the Philippines demonstrate positive income employment and consumption effects for poor households adopting small-pond or cage aquaculture systems. Overall, however, *greater gains for wider food security can be expected from SME development of specialist aquaculture*. The policy emphasis in aquaculture development is therefore shifting away from aquaculture as an income- a supply of fish to lower-income consumers. Larger-scale enterprises and SMEs, which don’t face the constraints to investment that small, resource-poor farmers do, are now thought to be a better target for aquaculture investment in the service of wider food security. This support for a mix of small-scale and larger scale aquaculture parallels developments in agriculture, where calls for support to smallholders to reduce the numbers of the rural poor co-exist with support for commercialization of agriculture to accelerate its role in promoting macroeconomic growth. The aggregate data on Asian aquaculture all show increases in the volume and value of trade, increased contribution of production to agricultural GDP, and, in some cases, increased availability of fish in domestic supply as well. That this translates into improved food security and reduced incidence or prevalence of poverty is then often simply assumed, although this is not necessarily the case if revenues accrue largely to a small number of wealthy people, or the growing middle classes in Asian cities increase their fish consumption, but nothing changes for the poor and hungry. Deeper analysis is needed before causal linkages can be inferred and poverty and food security benefits for aquaculture can be claimed.[24]

Belton & Little (2011) carried out a review of the evidence which, though heavily weighted towards examples from Bangladesh, suggests that the performance of externally funded aquaculture development interventions has generally been either underwhelming or difficult to divine on the basis of available information. This does not necessarily preclude the possibility that modest production gains generated by the more successful of such efforts may enhance the resilience of those targeted to seasonality and crises. In addition, the specificity of the Asian context in these studies needs to be accounted for when looking at other geographical areas. Nevertheless Haque et al.

(2010) explain relatively high levels of uptake and retention of a novel form of fish culture introduced by a project (rice field-based tilapia seed production), despite low financial returns, with reference to the cumulative and mutually reinforcing effect of numerous individual agro-ecological, socio-cultural and seasonal factors which appear insignificant if considered discretely. Lovshin et al. (2000) offer a similar but converse example from Latin America involving two projects which provided assistance for pond construction for aquaculture, in which most pond owners subsequently quit fish culture or continued at very low levels, but persisted in using ponds for a diverse range of other functions long after the project ended. In this light it seems possible that other positive outcomes related to the multi-functional nature of aquaculture introduced through interventions may be overlooked because they do not readily lend themselves to measurement using standard impact-evaluation methods. For example, the increased availability of cultured fish to producing households may result in reduced consumption expenditure on fish from other sources which, rather than raising incomes directly, may be diverted to the purchase of other foods or productive assets, or, as Haque et al. (2010) suggest, may reduce variability in income or hungry gaps through regular or counter-seasonal sales[25].

Aquaculture impact in Africa

Aquaculture is a major food production sector in Asia (over 50 million tonnes a year), while in Africa, production just reached 1 million tonnes. The poor performance of aquaculture in Africa has resulted in little investment in the sector in recent years but this is beginning to change in response to the growing gap between fish demand and supply and signs that historical constraints to aquaculture development on the continent are being overcome (Beveridge et al., 2010).

With respect to smallholder systems, a focus in Africa has been on the farm pond as an integral part of the farming system, supporting the production not only of fish but also offering flexibility to farmers in the use of water for irrigation and household needs to reduce vulnerability to rainfall variability, particularly in the context of climate change. Ex-post analysis of the development of small-scale integrated aquaculture in Malawi, which has led to an increase in the number of fish ponds from 300 to 7 000 over the past 25 years, has quantified the following mean benefits accruing to farms incorporating fish ponds into their farming systems (Dey et al., 2007):

- 10 percent improvement in total farm productivity;
- 134 percent increase in per hectare farm income;
- 61 percent increase in total farm income;
- 40 percent increase in technical efficiency (financial input-output ratio), and
- 208% increase in household consumption of fresh fish and 21% increase consumption of dried fish.

The benefits to food security - both through increases in income and direct consumption of fish – are clear, but they accrue to relatively small numbers of people. Total production of farmed fish is still only a small fraction of total supply in Malawi, and in all other African countries apart from Egypt. And the numbers of farmers with ponds is a minute fraction of the number of smallholder farmers in Africa. Growth of the sector continues to be limited by the water and other resource constraints of small-scale farmers and by weak input and output markets and limited access to technologies and knowledge.

Analysis of performance success in Egypt, Cameroon, Ghana, Nigeria and Uganda shows that fish production begins to significantly contribute to fish supply and trade where conditions support the emergence of small and medium-scale aquaculture enterprises with a more commercial orientation. Where links to output markets are strong – such as near urban centers and where the technologies and expertise have been available, entrepreneurs have seized opportunities to specialize in fish production (Beveridge et al., 2010). The impact of such development in Africa on food security, employment creation and revenue generation has not yet been evaluated, and studies such as those conducted by Stanley (2003) on the economic impacts of shrimp aquaculture in Honduras are recommended. However, as the majority of aquaculture in Africa to date has been orientated towards domestic and regional markets, rather than developed-country ones, the controversies around food security and export of fish that exist with respect to aquaculture in Asia

and capture fisheries in LDCs and LIFDCs have not yet arisen in Africa.[26]

Impact on nutrition security

Kawarazuka's (2010) study examined the pathways through which aquaculture can contribute to dietary intake of the households engaging in aquaculture activities. Household income from aquaculture is important as it can enhance purchasing power thereby increasing both quantity and quality of the diet. Aquaculture can bring synergy with agriculture productivity and profitability and contribute to improving dietary intake. In this respect, rice-fish farming and vegetable cultivation on the dikes of ponds have potential to improve dietary intake. The study shows that fish produced by aquaculture was kept for household consumption to some extent.
The direct effect of increased fish consumption on dietary intake was not clear but in the cases of the polyculture of nutrient-dense small indigenous fish species with carps and prawns, significant increase in micronutrient intake was projected from trial interventions. Therefore, disseminating polyculture in already existing fish ponds with large fish has the potential to reduce micronutrient deficiencies and their adverse health consequences. Women's participation in aquaculture may have certain effects on improving nutritional status but the pathways are not clear and this needs specific strategies in interventions to ensure participation of women. Aquaculture interventions could have positive impacts on the people living with HIV and AIDS as it can help to attain their increasing nutritional needs and sustain livelihoods with lower intensive work. It seems to be difficult to show nutritional outcomes in short term interventions focusing on aquaculture alone without addressing other factors which determine nutritional status. Nevertheless, as a case study in Malawi demonstrated (Aiga et al., 2009), aquaculture can be one factor among others which contribute to improved nutritional status, and this kind of study may be useful for linking the role of aquaculture to nutrition.[27]

Impact on fisheries

Evidence presented by Naylor et al. (2000) shows that total world aquaculture production currently adds to net global fish supplies although many types of aquaculture result in a net loss of fish. Aquaculture's potential contribution to fish supplies is severely diminished by the rapid growth in production of species fed carnivorous diets and by aquaculture practices that lead to coastal habitat destruction, biological pollution, and discharge of untreated effluents. Continued expansion of aquaculture requires healthy coastal and freshwater ecosystems. Without clear recognition of the industry's dependence on natural ecosystems, it is unlikely that aquaculture will develop to its full potential or will continue to supplement ocean fisheries.[28]

Small pelagic fish comprise around 30% of marine capture fisheries landings, with the proportion going into fishmeal production decreasing since the 1990s, as aquaculture producers aim to substitute fishmeal for other feeds to reduce input costs. Overall, it seems likely that a combination of improved catch regulations to sustain stocks of pelagic fish, coupled with feed innovation, will send price signals to aquaculture producers that will encourage innovation to reduce dependence on pelagic fish catches as a source of aquaculture feeds. It is unlikely these sources will be eliminated, but they may be reduced, giving space for innovation in ways to supply these fish directly to low income consumers in developing countries.[29]

4. Challenges for the development of sustainable aquaculture

Risk analysis is less commonly used to achieve successful and sustainable aquaculture by assessing the risks to aquaculture posed by the physical, social and economic environment in which it takes place. These include reduction of environmental risks (e.g. due to poor siting or severe weather events), biological risks (infection by pathogens via transfer from native stocks, predation by seals and sharks; red tides, etc.), operational risks (poor planning, work-related injuries), financial risks (e.g. market changes, currency fluctuations, emergence of new competitors, etc.) and social risks (negative image and resulting product boycott, lack of skilled manpower, competition from other sectors).[30] Many reports suggest that in the decades to come aquaculture's greatest challenge is to bridge the gap between growing market demand for aquatic products and supply from capture fisheries. Whilst developing new technologies to increase productivity is important, the challenge lies in increasing production in a sustainable way. Sustainable aquaculture development seeks sustainability under three dimensions, i.e. economic, social and environmental. Ensuring social sustainability is necessary for aquaculture to make sure that the benefits of aquaculture development are equitably shared.[31]

Risks of major environmental and human-health problems need to be weighed against achieving a more cautious rise in production that is, in the longer term, sustainable. The challenge of aquaculture lies in achieving systems which are simultaneously environmentally sound, socially oriented and economically sustainable. Only this way will its full potential be truly exploited.

4.1. Challenges to economic sustainability

Economical sustainability is expressed by the idea of self-maintaining growth. It is based on a series of macroeconomic principles related to balancing the budget, current account balance, inflation control, and so on, and basic investment rules, such as budgetary allocations, investment sector rates, capital ratio, productivity levels, consumption/saving ratios, and so on. These are intended to optimize growth without saddling future generations with excessive debt[32].

Competition within aquaculture

Aquaculture has become an increasingly commercial business in the new millennium. While competition is a positive factor that benefits consumers with lowered prices and motivates technological advances, species diversification, new markets and quality improvement (FAO, 2006), harsh competition may disrupt the industry and cause serious damages in the short run, especially when fish farmers, under the pressure of low profit margins, choose to adopt unsustainable farming practices (Bai, 2008). Competition has also led to trade disputes. Seafood exporting countries (mostly developing countries) complained that importing countries (mostly developed countries) used antidumping tariffs, stringent market standards or other barriers to protect inefficient domestic industries, while importing countries accused seafood exporters of gaining unfair competitive advantage through ignoring environmental and social costs and asked for leveling of the playing field.

Although it is not sensible or possible for fish farmers to form a cartel to limit production for higher revenues, fish farmers as well as policymakers should understand that demand for seafood is constrained by people's incomes and preferences, and that increasing the supply to already saturated markets would only lower prices without increasing revenues. While boom-bust cycles may be a common adjustment process under the competitive market mechanism, severe price fluctuations tend to cause hardships for fish farmers, especially small-holder fish farmers who lack bargaining power and tend to be price-takers in both input-purchasing and output-selling markets. How to avoid flooding the market is a challenge faced by fish farmers that compete for common markets (Lovatelli *et al.,* 2008). When there is excess supply in international markets, governments tend to stabilize seafood prices by promoting domestic consumption and helping fish farmers explore other markets. While such remedies are helpful, it is equally important to provide timely information about market demand and competition conditions at all levels (i.e. global, regional, domestic, and local) to prevent market glut. Modern information technology (e.g. Internet) makes such information a valuable yet affordable public good

that can benefit many stakeholders and lead to more orderly market conditions.

Availability and increased demand for feed resources

All finfish and crustacean farming systems are dependent upon the market availability of `feed resources' for the provision of nutrient inputs, either in the form of fertilizers, agricultural wastes and by-products as supplementary feeds, or formulated pelleted aquafeeds. It follows therefore that if the finfish and crustacean aquaculture sector is to maintain its current growth rate (increasing by 11.2% from 10.90 mmt to 12.12 mmt from 1992 to 1993) then it will have to compete with other users (ie. humans and/or farm livestock) for these feed resources. Although the aquaculture sector may have been successful in the past in obtaining the necessary fertilizer and feed inputs, this may not be so in the future as farming systems intensify and the demand for a finite pool of valuable feed resources increases. It has been estimated that the total world production of manufactured compound animal feeds exceeded 550 mmt in 1994 (valued at over 55 US$ thousand million), of which poultry feeds constituted 32%, pig feeds 31%, dairy feeds 17%, beef feeds 11%, aquatic feeds 3%, and others 6%.[33]

Disease

Diseases are a primary constraint to the growth of the aquaculture sector in many parts of the world. A multitude of factors has contributed to the health problems currently faced by aquaculture. Over the past three decades, aquaculture has expanded, intensified, and diversified, based heavily on movements of live aquatic animals and animal products (broodstock, seed, and feed).
New outlooks and directions have accelerated the accidental spread and incursion of diseases into new populations and geographic regions, for example, through movements of hatchery produced stocks, new species for culture, enhancement and development of the ornamental fish trade. Translocation of pathogens and diseases with movements of their hosts is by no means a new phenomenon. Advances in live aquatic animal trade, facilitated by improved transportation efficiency, are now recognized as having played a pivotal role in the introduction and spread of pathogens and diseases into many aquaculture systems.

There is now convincing evidence of the serious socio-economic, environmental and international tradeconsequences arising from trans-boundary aquatic animal diseases (Arthur and Ogawa, 1996; Subasinghe et al., 2001). For instance, combined losses from shrimp diseases, at the global level from 11 countries for the period 1987–1994, were estimated at US$ 3019 M (Israngkura and Sae-Hae, 2002). More recent examples of major losses due to spread of aquatic animal diseases include that of carp mortalities (losses estimated at US$ 50 B rupiah, approximately US$ 5.5 M) in Indonesia (NACA/ACIAR, 2002); koi herpes virus (KHV) (losses estimated at 150 M yen, approximately US$ 1.4 M) in Japan (Pro-Med News, 2003a); and abalone mortalities (losses estimated at 400 M TWD, approximately US$ 11.4 M) in Taiwan, Province of China (Pro-Med News, 2003b).

The aquatic environment is a complex ecosystem, which makes the distinction between health, sub-optimal performance and disease obscure. During disease outbreaks, the underlying cause is often difficult to ascertain and is usually the end result of a series of linked events involving environmental factors, health condition of the stocks, presence of an infectious agent and/or poor husbandry and management practices. The whole aquatic production environment, including ecological processes, must be taken into consideration. Therefore, an aquatic system health management approach needs to be developed to replace the more traditional pathogen-focused approach applied traditionally to disease diagnosis.[34]This means leaving behind the decade of disease treatment with all the negative environmental and other consequences, and move to a future of disease prevention. Disease control in aquaculture should focus first on preventive measures related to good management practices that maintain good water quality, with better/certified seed, less stress, high-quality feeds etc. In most farming practices, there is still plenty of room for improvement on many of these counts. More applied research should better document these effects. More basic knowledge is needed of the microbial, viral and parasitic diseases and their epidemiology in aquatic organisms. Access to a large arsenal of molecular techniques will certainly assist in quick progress in this area.[35]

Smallholder-specific challenges to the development of economically sustainable aquaculture

The positive impacts of globalization include worldwide marketing of goods and services; increased economies of scale; and corporate governance of the industrial food production sectors taking advantage of inexpensive labour, capital and technology. There is, however, good evidence that while the industrial and corporate sectors continue to benefit from globalization, small-scale producers are slowly being pushed out of business due to competition. The combined effects of trade liberalization and globalization have increased economic differentiation among communities and households. In addition, state withdrawal from agricultural marketing has contributed to a highly uncertain environment in which input and output prices are determined by the market, often favouring large-scale producers who are better equipped to manage price variability and/or absorb price shocks and to gain through efficiencies of scale in commodity production. It is clear that increasing globalization and the resultant trade liberalization of aquaculture products is leading towards the marginalization and exclusion of individual small-scale producers, who *face major challenges to remain competitive and to participate in modern value chains globally.* The situation is particularly serious in Asia, due to the large numbers of people involved but the trend affects farmers across the aquaculture-producing regions. This is partly due to integration of production-distribution chains and coordinated exchange between aquaculture farmers, processors and retailers, and is evident in the higher-value internationally traded export species such as shrimp, although this trend is now also affecting low-value species such as catfish and tilapia in some countries.

Quality and food safety standards

Small-scale producers face challenges related to the changing preferences of consumers for safer, healthier, better quality food produced in environmentally sustainable and ethical ways. This has resulted in increased demand for food safety and environmental standards, or “niche” products that have special characteristics based on their quality, farming practice and origin. These characteristics are strongly linked to how products are being produced rather than to the end product itself, thus, putting greater emphasis on traceability. Growing customer awareness has also led to the development of several aquaculture certification schemes, making it no longer enough for aquaculture farmers to pay attention solely to efficient production. These increased demands for meeting food safety standards, traceability, certification and other non-tariff requirements are driving risks and costs down the market chain to the farmer, favouring medium to large-scale, capital-intensive operations that can afford such extra costs and excluding small-scale farmers who have limited resources and capacity to meet these requirements.

Market access

To remain competitive, there is a need to change the management of both large and small-scale producers. Large-scale farmers have a much higher adaptive capacity to benefit from such trends than do small-scale farmers. Small-scale aquaculture farmers are not only exposed to increasing market risks, but also face enormous constraints in accessing markets and services and integrating into modern supply chains. In many cases, they are ill-equipped to benefit fully from the new market environment and knowledge because of lack of public and private policy and services to support investment and change, resulting in potentially significant social risks for many rural producers.

Taking *Litopenaeus vannamei* (whiteleg shrimp) farming as an example, the market price fluctuates tremendously as production volume increases, thus making it difficult for small-scale farmers to make a profit from small-scaleproduction. Besides farm-gate price, there is a significant difference in productivity between small-scale farmers and large-scale corporate farms. In Thailand, the difference in productivity between small-scale and large scale farming of *L. vannamei* is almost three times (Figure 3). The low productivity of small-scale aquaculture producers compared to larger enterprises has also been noted in various studies (e.g. Brummet, Lazard and Moehl, 2008).

Market access remains very important for small-scale producers and for rural development in general. In developing countries, especially in poor rural areas, markets are

often thin (with low volume of trade or a low number of transactions) or fail completely due to the high costs and risks of participation. However, avoiding markets is not a realistic solution for most small-scale producers, particularly those who seek commercial income gains from their investments into aquaculture ponds. With small-scale producers facing many general challenges (including limited land and capital, dispersed locations, limited transport and communications infrastructure, poor health and social and political marginalization), markets have the potential to help them overcome these challenges by providing income, generating employment, reducing poverty, empowering small-scale producers, fostering self-reliance and promoting pro-poor economic growth through enabling consumption linkages resulting in multiplier effects on growth (Penrose-Buckley, 2007).[36]

4.2. Challenges to social sustainability

Social sustainability encompasses human rights, labor rights, and corporate governance. In common with environmental sustainability, social sustainability is the idea that future generations should have the same or greater access to social resources as the current generation ("inter-generational equity"), while there should also be equal access to social resources within the current generation ("intra-generational equity").[37]The social dimension of sustainable development raises the issue of how to transmit sufficient assets and potentialities from one generation to the next. As well as physical and financial capital, these assets include human capital (including education and health), social capital (based on social interactions), rights, values, and so on, as well as the capacity to use all these potentialities in an appropriate way.[38]

Equity and access to resources

Technological advances almost universally help the rich more than the poor; the rich use them to their advantage (Kent, 1976). Policies have often failed to correct the social and institutional inadequacies or constraints preventing wider participation of small-scale farmers in new technologies. Culture of high-value fish and shrimp targeted for export markets continues to receive substantial policy incentives such targeted for export markets continues to receive substantial policy incentives such as cheap land leases, credit supply and low tariffs on imported inputs and infrastructure, where benefit tends to favor the richer entrepreneurs (Ahmed, 1997, 1999). These policies provide economic incentives to the rich fish farmers to operate at a low level of marginal productivity from the subsidized inputs (e.g., land) and offer a higher price for competitive inputs such as feed, which involve diverting food-fish into fishmeal and animal feed. Their products are often targeted to up-scale (e.g., urban) and export markets, implying a net transfer of food and income away from the poor (Ahmed, 1997).

Access to resources

Equitable and fairer access to resources utilized for aquaculture is an important policy issue. Empirical results from Asian countries, particularly those in rural and agricultural settings, have shown the great importance of land and water (pond) in the portfolio of the rural household. Ownership or rights over access to land and water played an important role in determining who would primarily benefit from aquaculture development in Bangladesh (Ahmed et al., 1993; Lewis, 1998). From a survey of two thanas (sub-districts) it was evident that there exists a strong positive association between pond and land ownership and farm size group of the households, implying a lower possible benefit for landless and assetless households from a general development of aquaculture (Table 2).

Evidence also suggests that the richer people established a greater claim on the land and water resources that over the years were brought under aquaculture practices. Even in cases where landless and poor people initially held the ponds and waterbodies through lease and other arrangements, rich owners re-exerted their claims over them as soon as the high profitability from aquaculture was revealed (Lewis, 1998). Likewise, liberal government policies on land use encouraged large scale conversion of public lands (e.g., mangroves, coastal lakes and lagoons) into aquaculture holdings at minimal rent (Ahmed, 1999). This, in many cases, took away the common property and subsistence-oriented activities such

as fishing by the poorer segments of the population, while the negative environmental effects extended into the adjoining ecosystems such as rice fields and wetlands creating an outright inequity and increased social and political tension (Alauddin and Tisdell, 1998). The benefit or net returns from the adoption of aquaculture technology will depend foremost on the accessibility to or ownership of principal production factors, such as land (including water), labor and capital. The study by Veerina et al. (1993) on aquaculture development in Andra Pradesh, India revealed that mostly landed people adopted aquaculture, where about 85% of the farms were owned. In targeting the poorer sector to undertake aquaculture even at a smaller scale, the lack of access to land and water would be a major constraint, warranting a more targeted and institutional approach to rural aquaculture development (Lewis, 1998).

Despite the resource constraints, the poor and subsistence-oriented households have also demonstrated a greater ability to participate and benefit from aquaculture in situations where wider options on technology choices (e.g., species combination, stocking density and feeding) and opportunities for marketing were made available to them (Gupta et al., 1998, p. 90; Ahmed et al., 1995). The level of aquaculture information available to farmers proved to be very crucial. Availability of programs focusing on intensive information dissemination and training schemes on the various technology choices have shown positive effects on the adoption rate of aquaculture technology, as evidenced by an increase in the number and area of fishponds as well as adoption of improved aquaculture technology (Ahmed et al., 1995; Thompson et al., 2000).

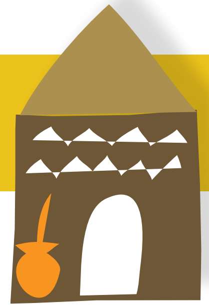
Competition and bargaining power of small-scale producers

In most parts of the world, small-scale producers (e.g., fishers), especially the subsistence-oriented operators, have poor bargaining power. Given the wide evidence of exploitation of fishers and extraction of rent by traders and middle agents, small farmers who lack bargaining power will naturally have to compete against organized marketing agents, and are likely to suffer from similar consequences.

Likewise, if farmers depend only on the local village markets to sell their fish products there will be a tendency for overproduction and increased fish supply in the rural markets. Due to low purchasing power, slower growth of income and lower income elasticity of demand, any reduction in the price of fish due to increased supply may not necessarily result in a proportionate increase in the fish consumption levels of rural households (Ahmed et al., 1995). This implies that fish farmers need to expand their market outlets (e.g., to urban areas) or are likely to face a more competitive price for their produce. The demand for fish in the urban market is evidently higher; the urban consumers have higher purchasing power; and there is an increasing trend in urban fish consumption (Veerina et al., 1993, 1999; Ahmedet al., 1993; ICLARM, 1998).[39]

Equity and gender perspective in aquaculture development

While most fishing activities are dominated by men, there is a need to acknowledge the critical role of women and their increased involvement in all aspects and stages of aquaculture. In some countries, women are excluded and are often not allowed to work in fishponds, except for collecting shellfish off the beach, while in some countries women lack the rights to own land or ponds (Nash, 1995). However, in most Southeast Asian countries, women actively participate in farming. In these countries women have assumed a major role in the growth of the aquaculture sector. They are actively involved in the feeding and harvesting of fish and likewise in the processing of the fish catch. Nevertheless, despite the critical role they play, most of them still lack access to physical and capital resources, and training and education. In anticipation of the increased workload of women, and given the current development efforts in the aquaculture sector, there is also a need to redirect some policies towards improving the efficiency and profitability of female labor, by providing greater access to critical resources and services and training to the women members of the household. In Bangladesh, functionally landless people (less than 0.5 acre) became profitably involved in aquaculture in NGO-administered project sites. Women from resource-poor and asset-less households can also participate if institutional constraints are reduced or minimized as demonstrated by NGO-administered projects



(Watanabe, 1993; Gupta et al., 1999). This can contribute to empowerment of women, and play a significant role in household nutrition. One should also look at how aquaculture will add to the workload of the women within the household in a traditional family structure, and how women will respond to the demanding nature of aquaculture activities vis-à-vis traditional and obligatory familial responsibilities (e.g., child care and home making).[40]

Employment conditions

There are well-documented cases of unfair employment practices in aquaculture. For example, there are some research findings according to which aquaculture enterprises, especially large corporations, exploit local labour. One study argue that local labour is employed in lower-paid jobs, paid low salaries, and subjected to discriminatory practices such as willingly creating gender imbalances or paying female workers less than male workers doing the same jobs.[41] Child labour employment, for example, in factories, processing units, peeling sheds, and in the collection of shrimp seeds, is also sometimes highlighted.[42] There is a need for more research into this issue, as there are sufficient indications to suggest that these practices might occur on a large scale, especially in developing countries for economic reasons. Most countries have labour legislation to protect workers. However, compliance with such legislation can result in high indirect costs and deter firms, especially when goods are intended for export. Where these costs are high for firms and differ amply across borders, they can give enterprises operating in countries with lower labour and social standards a competitive advantage compared with those in jurisdictions with higher standards. A possible result is that governments will be under pressure from companies to reduce labour and social standards in order to ease the burden of high indirect labour costs, thereby enhancing their competitive edge. This pattern of behaviour becomes possible because large companies farming some species (such as shrimp, salmon, tilapia, abalone and others that become global commodities) are generally located in isolated rural communities, which gives them power over the labour force as the sole or dominant employer. Workers in these communities may also accept reduced wages and salaries, work longer hours without compensation or forgo some benefits. A thorough understanding of these and other aspects of governance of employment in aquaculture will assist policy-makers in implementing corrective measures or in taking preventive action.[43]

Social cohesion and community-level challenges

Social acceptability is an integral part of sustainability. However, it has usually become an issue for aquaculture planners and developers only after sections of the population have demonstrated discontent through conflict or litigation. While aquaculture can contribute to economic growth, it can also create social disruption and inequalities.

Conflict over resource allocation and resentment over hiring practices as well as negative environmental externalities are part of the social risks of aquaculture (Bueno, 2008). This can be particularly acute if small elites, domestic or foreign, dominate the industry. Experiences in many countries indicate that when profit-driven aquaculture results in a large amount of resources flowing into the production of a highly profitable single crop (e.g. shrimp), some local people are able to grab them opportunity and become better off, while others are marginalized because of various constraints; and worse still, their requirements for livelihood and environment were often neglected (Barraclough and Finger-Stich, 1996). The resulting increase in inequality tends to cause social conflicts.

When export-led commercial aquaculture opens rural communities to the outside world, the traditional values and way of life tend to be impacted. People may become more open, ambitious and competitive and pay increasing attention to financial success. Traditional customs and the cultural heritages of indigenous people may be suppressed by profit-seeking aquaculture activities.As a highly profitable and regulated business, aquaculture development may foster rent-seeking behaviours. While such impacts have complicated and significant implications for stakeholders' social well-being, research in this area is generally lacking.[44] Rapid aquaculture development may also attract immigration of labour to local communities, which would nevertheless put pressure on the original social order and cause social conflicts (Rijsberman, 1999; Lewins 2006).[45]

4.3. Challenges to environmental sustainability

Aquaculture faces the challenge of achieving environmental sustainability. Lack of sustainability is a result of either negative environmental impacts of aquaculture development or of environmental impacts on aquculture caused by non-aquaculture activities, such as climate change.

Resource interactions and dependencies

(i) Land water and energy

While beneficial in many ways, the growth of aquaculture is increasing pressure on natural resource inputs, notably water, energy and feed, although sites in a broader sense are also an issue. There is also the question of the use of, and impact on, environmental services, particularly for the dispersion and treatment of farm effluents. Aquaculture systems are very diverse with respect to their dependence on these resources (table below).

Table 4. Typical aquaculture resource demands by species. Sources: Muir & Beveridge (1987), Phillips *et al.* (1991), EIFAC (2000), FAO (2000), Green & Engle (2000), Troell *et al.* (2004) and Tyedmers *et al.* (2007). Protein energy per tonne for all fish/shellfish species = 4.73 GJ; for aquatic plants = 3.55 GJ.

	production per unit area (land or water) t ha^{-1}	water use per unit of production '000 m^3 $tonne^{-1}$	input : output energy ratio	system features
salmon, trout and other salmonids	1750	2260[a]	50	intensively fed cage/ponds
sea bass, bream and similar	1125	2500	40	intensively fed cages
halibut, turbot, sole, etc.	2676	2000	45	intensive onshore tanks
cod, haddock, hake, etc.	1200	2500	45	experimental cage systems
carp, tilapia, catfish	2	5[a]	30	fertilized ponds
eels, sturgeon, perch, zander, etc.	190	0.1[a]	35	extensive stocked water bodies
tuna	300	3000	50	intensively fed cages
mussels	76	3000	10	raft or longline systems
oysters and scallops	25	2000	5	rafts or longlines—lanterns
clams, cockles, etc.	0.5	2000	5	extensive coastal beds
new non-fish aquaculture sp.	150	0.2	20	range of systems
aquatic plants	1	2000	1	coastal beds/stakes and lines

[a]Water consumption is mainly of concern in freshwater systems (the category salmon and trout covers a mix of both freshwater and sea water). These figures contrast with those of Verdegem & Bosma (2009) who estimated total water withdrawal for freshwater aquaculture at 16 900 m^3 $tonne^{-1}$, although this does not take account of water returned to the aquifer.

Freshwater farming uses a range of systems, from static water ponds through to high flow-through tanks. Most involve intake of water from the environment and a post-production effluent stream, so that water consumption does not equate to water intake. However, the quality of discharge water is usually diminished and water can be lost through evaporation and seepage. As a worst case, pond systems in tropical countries can lose 20 per cent of their volume per day (Beveridge 2004).

However, pond aquaculture can also contribute to water management as it acts to catch and store surface water (rain and run-off) that might otherwise be lost from local agroecosystems or which might cause damaging floods (e.g. in the Czech Republic). Implementation of water reuse and recirculation systems can reduce consumption substantially, although usually at the cost of higher energy inputs.

The majority of freshwater aquaculture is pond based using semi-intensive methods that rely on controlled eutrophication for their productivity, using a wide variety of organic and inorganic fertilizers as well as supplementary feedstuffs. The production of feed materials for aquaculture, particularly grain and similar crops, incurs additional freshwater use (up to 3000 m^3

tonne21 according to Verdegem & Bosma 2009). Solid wastes produced from such systems often have a use as fertilizers for other crops. Dissolved nutrients can often be lost through necessary water replacement regimes and sometimes cause problems in areas with extensive aquaculture production or with otherwise oligotroiphic or mesotrophic environments.

Better optimization of freshwater production systems with respect to water and feed management could triple production without increasing freshwater usage according to Verdegem & Bosma (2009). Given the presently increasing pressures on freshwater supplies, future aquaculture development might be expected to utilize more abundant brackish and sea water resources. However, environmental issues are no less complex.

Aquaculture will have to compete with agriculture as well as industrial and domestic users for a limited water supply which may often be supporting a growing population. Water stress due to decreased precipitation and/or increased evaporation may limit aquaculture in some areas. This may take the form of increased risks associated with a reduced water supply on a continual basis, or by reducing the length of a routine growing season. Increased variation in precipitation patterns and droughts may increase the risk and costs of aquaculture in some areas as provision for these extremes has to be made.

(ii) Productivity in relation to energy inputs

Table 5. Total embodied energy relationships, for equivalent area. Developed from Muir (2005), Troell *et al.* (2004) and Tyedmers *et al.* (2007).

quantity	seaweed culture	mussel culture	cage salmonid culture
energy inputs (kcal × 10^5)			
solar/renewable (%)	0.30 (4.5%)	0.75–2.05 (71.4–85.4%)	470–830 (81.0–87.4%)
fossil/non-renewable (%)	6.35 (95.5%)	0.30–0.35 (28.6–14.6%)	110–120 (19.0–12.6%)
total energy	6.65	1.05–2.40	580–950
protein output (kcal)	6605	255–440	22 420
input/output ratio	100	410–545	2585–4235

The energy cost and linked implications for carbon emissions of aquaculture activities is receiving greater attention. A distinction needs to be drawn in analysis between direct energy use (e.g. fuel and electricity consumed directly in the production process) and the more comprehensive approaches to auditing energy inputs. For instance, these may include consideration of industrial energy (energy used in the manufacture and supply of equipment, feeds and other inputs) or embodied energy, which also takes into account photosynthesis and sunlight energy or calorific values, etc. Another consideration is whether the energy sources are renewable or not.

Life cycle analysis (LCA) carried out by Tyedmers & Pelletier (2007) found energy dependence correlated with production intensity. This is mainly due to the energy input in the production and delivery of feed (Gronroos et al. 2006). More variable is the energy required for other on-farm activities which can range from virtually zero up to about 3 kWh kg21. For land-based farms, most of the power is likely to be provided by electricity from the central grid. Cage-based farms rely mainly on diesel or other fossil fuel. Table 5 shows typical embodied energy levels and ratios for different production systems, with seaweed and mussel culture requiring much more modest input levels.

(iii) Coastal zone pressures and eco system impacts

Aquaculture, especially in coastal zones, is frequently in competition with other uses of the resource that can often take precedence (e.g. tourism and port developments). However, there are also cases where aquaculture has outcompeted other users, such as shrimp farming, which has come under scrutiny due to over-exploitation and destruction of mangrove resources, as well as other environmental impacts and serious disease problems.[46] Hundreds of thousands of hectares of mangroves

and coastal wetlands have been transformed into milk-fish and shrimp ponds. This transformation results in the loss of essential ecosystem services generated by mangroves including the provision of nursery habitats, coastal protection, flood control, sediment trapping and water treatment. Mangroves are also linked closely to habitat conditions of coral reefs and seagrass beds. The loss in wild fisheries stocks due to habitat conversion associated with shrimp farming is large , estimated at about 440-447g of wild fish biomass lost per kilogram of shrimp raised.[47] The wider ecosystem value of these environments is now recognized and suitable protection given in most regions, although much remains to be done with respect to rebuilding lost area. More recent moves by the shrimp industry inland have also caused problems with saline intrusion into agricultural soils.

The development of marine fish farming in cages has also raised concerns over wider environmental, ecosystem and biodiversity impacts. At modest scales of development, these are hard to detect apart from localized changes to sediments beneath the cages. Larger scale development has the potential for wider impacts due to the release of nutrient or chemical wastes directly into the environment, or the effects of escaped fish or disease transfer on wild populations. The most immediate problem is often conflicts between cage-based farming and other interests, such as boating and navigation, preservation of seascape scenery and protection of wildlife. In Europe, these issues are considered during the licensing process or increasingly through the development of coastal zone plans. Similar issues apply to coastal pond and pump-ashore tank systems.

iv) Wild species

Aquaculture can help preserve wild fish stocks by supplying more affordable aquatic products and hence reducing the pressure on fisheries (Tisdell, 2004). Aquaculture can also increase wild fish stocks through restocking programmes (Petr, 1998). However, environmental degradation caused by aquaculture may negatively affect wild species. In addition, *collection of wild seed and broodstock,* introduction of exotic species and aquaculture escapees may also have negative impacts on wild stocks (FAO, 2006; World Bank, 2006). Most aquaculture species still rely on wild stocks for seed or broodstock. As collection of wild seed and broodstock tends to damage not only the targeted wild stocks but also those of by-catch species, increasing public concerns over biodiversity have put it under stricter scrutiny and regulation; some countries (e.g. Egypt) have established official fry collection centers or have used licensing to regulate such activities (FAO, 2006). However, because in some countries wild seed and broodstock collection is a lucrative business providing the livelihoods for many low-income people, public attempts to restrict it tend to be difficult because of social pressure, or they may not be effective because of black markets (FAO, 2006). Advances in artificial breeding technology have helped reduce aquaculture's dependence upon wild seed resources for an increasing number of species (milkfish, tiger prawn, mangrove crabs, etc.). The scarcity of seed resources is expected to continue driving progress in artificial breeding through the market mechanism, while more public supports and better partnership between scientific researchers and the private sector are needed to speed up the process (FAO, 2006).[48]

Other controversial issues include the *introduction of exotic species* and aquaculture escapees, which may negatively affect wild stocks through habitat competition, disease spread and gene contamination (APEC/FAO/NACA/SEMARNAP, 2001). Genetically-improved farmed species, once let into the wild environment, may intrude genetic integrity and cause ecological disruption (Naylor et al., 2005). While the damaging impacts of farmed species in the wild are not entirely clear, public concerns over biodiversity and bio-security have led to stricter regulations (e.g. requirement of import risk assessment) prior to introducing new species or strains for aquaculture (FAO, 2006, Arthur et al., 2009). Various measures (e.g. removal of escapees as a precondition for farm licenses, selecting sites with least impacts on wild stocks) have been applied to reduce the impacts of farmed species on wild stocks; further studies on the impacts of cultured species on biodiversity are needed (World Bank, 2006).[49]

(v) Feeds

Most mollusk cultures requires no feed inputs and the majority of freshwater fish production utilizes low protein, grain-based supplementary diets and organic fertilizers. Much of the crustacean

farming, most marine species and other intensive fish aquaculture require a higher quality diet, usually containing fish meal and often fish oil. Some aquaculture, notably tuna fattening and much of the marine cage culture in Asia, relies directly on wild-caught small pelagic fish with relatively low market price. The process transforms fish protein from low to high value for human consumption. However, the efficiency of this is both an ecological issue and one of social justice (e.g. consumers of farmed salmon and shrimp may effectively outcompete rural poor for this fish resource; Tacon & Metian 2009).

In 2008, approximately 90 per cent of the fish oil available worldwide, and 71 per cent of the fish meal, was consumed in aquaculture practices (Tacon & Metian in preparation). Unless alternative higher value markets develop, aquaculture will continue to consume the majority of fish meal and oil produced but this will not be sufficient to meet ever-increasing demands for aquafeed ingredients. Feeds for herbivorous and omnivorous species (carps and tilapias) often contain fish meal and sometimes fish oil, although this is not essential on purely nutritional grounds. Rapidly expanding culture of carnivorous species such as cobia and pangasius catfish could increase the pressure on fish meal and oil supplies. Overall, the finite supply of fish meal and oil is not expected to be a major constraint, but demand for alternative feed materials will increase—in turn placing greater pressure on the wider agro-feed system.[50]

Food web interactions. Many small pelagic fisheries exploited for feed are over-fished and are strained by climate variability associated with EL Nino Southern Oscillation events. The impact of pelagic fisheries depletion is thought to reduce available food supplies for marine predators, including valuable species consumed by humans. In the North Sea, for example, over-exploitation of many capelin, sandeel and Norway pout stocks, mainly for reduction to fishmeal, has been implicated in the declines of certain stocks of other wild fish such as cod.[51]

vi) Aquaculture and climate change

Physical and biological climate-induced changes in marine and freshwater systems are being increasingly observed (Barange and Perry, 2009). The severity of climate change impacts on aquaculture are dependent on the nature (freshwater, brackish, marine) and location (tropical, temperate) of operations and on the direct and indirect impacts of climate change on the natural resources it requires, primarily water, land, seed, feed and energy (De Silva and Soto, 2009). Positive impacts of climate change on aquaculture include higher food conversion efficiencies and growth rates in warmer waters, increased length of the growing season and range expansions polewards owing to decreases in ice (Easterling et al., 2007). However, as capture fisheries provide major feed and seed inputs to aquaculture activities, variations in the quantity, quality and prices of these inputs will have direct repercussions on the overall efficiency of aquaculture systems. Allison et al. (2009) have identified the national economies most vulnerable to climate change because of their dependence on fish for employment, domestic and export incomes and dietary protein supply. However, the complexity of vulnerability, its uneven distribution and difficult prediction make the impacts of climate-related changes on those depending on aquaculture for their livelihoods as varied as the changes themselves (Daw et al., 2009). Leung's study of disease outbreak severity across different latitudes in a diverse range of aquaculture systems and showed that disease at lower latitudes progresses more rapidly and results in higher cumulative mortality, in particular at early stages of development and in shellfish. Tropical countries are expected to suffer proportionally greater losses in aquaculture during disease outbreaks and have less time to mitigate losses. As a consequence, disease can present a major problem for food production and security in equatorial regions where fish and shellfish provide a major source of dietary protein.[52]

Aquaculture presents some scope for adapting to climate change and mitigating its own impact on climate change. Although adaptation and mitigation measures should be commensurate with risk, they should become an integral component of aquaculture policies and/or strategies. To this end, and to overcome the additional pressure of climate change on improving governance in aquaculture development, the sector needs to engage with diverse stakeholders, including consumers, governments and allied or competing industries in order to create economic opportunities, in particular for vulnerable groups, while increasing

the long-term resilience of the sector to climate induced changes (FAO, 2008b).[53]

Building climate-resilient aquaculture

Resilience requires genetic and species diversity, low stress from other factors, and "healthy" and productive populations. Effective ecosystem approach to aquaculture (EAA) should lead to resilient social-ecological systems. In the face of uncertainty, aquaculture food production systems should be established which are diverse and relatively flexible, with integration and coordination of livestock and crop production. Aquaculture's ability to respond to disease shocks is through better site selection and vaccines in salmon, use of low and zero water exchange systems, the selective breeding of disease-free and disease resistant stocks in shrimp, and the introduction of new species in oysters.

Climate change and food safety

Climate change may also influence the safety of food harvested from marine and freshwater environments. There are two main areas that have the potential for change: microbial pathogens, and harmful algal blooms.

Microbial pathogens. Climate change is expected to accelerate the water cycle with increased precipitation in the tropics and at high altitudes, drier conditions in subtropics and increased frequencies of extreme droughts and floods. Events such as floods are likely to disrupt sanitary infrastructure around fish harvesting and aquaculture sites, affecting fish safety. The presence of Salmonella in rivers and the marine environment has been related to torrential rains and storm-generated flows, and the pathogen could thus reach aquaculture sites or contaminate fish in coastal waters. Outbreaks of illness caused by *Vibrio parahaemolyticus* in shellfish in Chile have been related to the arrival of warm equatorial water during El Niño events.

Harmful algal blooms. Harmful algal blooms are a completely natural phenomenon that have occurred throughout recorded history in all parts of the globe. Whereas wild fish stocks are free to swim away from problem areas, caged fish and shellfish are trapped and, thus, can suffer mortalities and/or become toxic. Of greatest concern to human society are algal species that produce potent neurotoxins that can find their way through shellfish and fish to consumers, where they cause a variety of gastrointestinal and neurological illnesses. Worldwide, almost 2 000 cases of food poisoning from consumption of contaminated fish or shellfish are reported each year. Some 15 percent of these cases prove fatal. In the past three decades, harmful algal blooms seem to have become more frequent, more intense and more widespread, in part ascribed to climate changes. The seafood industry (capture and farmed) must monitor for an increasing number of harmful algal species in the water column and for an increasing number of algal toxins in seafood products. Global climate change is adding a new level of uncertainty to many seafood safety monitoring programmes.[54]

5. Opportunities for aquaculture sustainable development

5.1 The drivers of sustainability

Various aspects have to be taken into account when considering the three interrelated dimensions of sustainable development. First, economic and social linkage can be used to tackle the social consequences of macroeconomic policies in terms of the poverty, vulnerability and inequality various groups are facing. Second, the interconnection between the ecological and social dimensions raises the issue of trade-off between reducing poverty, on one hand, and protecting the environment, on the other. Third, we must consider the social nexus itself, which deals with access to and accumulation of human and social resources, as well as with the links between poverty, vulnerability and inequality for various groups of people.[55] In addition, the challenges generated by a given aquaculture system vary depending on several factors, including: farming system in terms of size and extent of intensification, geography and location, species farmed etc. For instance, the environmental problems generated by shrimp farming also vary depending upon the shrimp production system adopted. While low intensity traditional and extensive shrimp farms are likely to cause greater destruction of mangroves than semi-intensive ones because of the larger area covered by such farms , the high yielding intensive and semi-intensive shrimp farms which occupy lesser area but rely on chemicals, fertilizers and antibiotics to boost shrimp output can degrade land and water quality. Hein (2002) notes that the development of traditional and extensive shrimp farms in the vicinity of Chilka lake, a Ramsar site in Orissa, India was leading to increased sedimentation in the lake, degradation of the protected habitat and changes in local hydrology. If well managed and regulated, technological upgrading can enhance productivity and reduce environmental spillovers. For instance, Anderson (2002) shows how management and technology use is a continuum from unregulated fisheries to regulated fisheries, extensive and then intensive aquaculture.[56]

Enabling environment

Subasinghe distinguishes several components of an enabling environment necessary to the development of sustainable aquaculture:

Policy and institutional and legal environment. Strong institutional capacity, that is, the ability of countries and organizations to strengthen and implement policy and regulatory frameworks that are both transparent and enforceable. Key recommendations that would help develop conducive institutional and policy environments include:

- developing clear aquaculture policy with a clearly defined lead agency with adequate organizational stature to play a strong coordinating role;

- developing comprehensive and enforceable laws, regulations and administrative procedures that encourage sustainable aquaculture and promote trade in aquaculture products, with a stakeholder participatory approach;

- targeting organizations and institutions dealing with administration, education, research and development, that represent the private sector, non-governmental organizations (NGOs), consumers and other stakeholders, in addition to government ministries and public-sector agencies;

- developing mechanisms and protocols for the timely collection and reporting of relevant data;

- sharing information on policies and legislation, rules and procedures that encompass good management practices in aquaculture;

- clarifying legal frameworks and policy objectives regarding access and user rights for farmers;

- improving the capacity of institutions to develop and implement strategies that target the aquaculture development needs of poorer communities.

Technology: Appropriate technologies contribute to aquaculture sustainability with a variety of mechanisms that can meet the needs of the local environment. Delivery of such techniques requires effective communication networks,

reliable data and a decision-making process that ensures aquaculture producers choose the best production systems and species for their environment.

Product quality and safety: Quality, safety and trade of aquaculture products are important aspects of a sustainable industry. It is therefore appropriate to mention that the importance of attaining sustainable aquaculture with negligible/minimal environmental or socio-economic impacts is forcing many exporting countries to adopt and implement more sustainable production practices. At a national level, safety and quality management systems should be put into place to ensure production, distribution and sale of aquaculture products are safe and of high quality. Such measures require competent professional associations that work in close association with the legal authority, in order to be successful.

Information: Access to, and effective dissemination of, reliable information is needed for informed decision-making and responsible actions at all levels. High-quality information supports policy and planning, improves application of research results, increases farmers' capabilities to address sustainable development and public awareness of achievements. Establishing effective national and regional information systems, with clear understanding of the role of the information for management of the sector is vital. Effective tools and methods to manage and analyze data (disciplinary, interdisciplinary and inter-sectoral) and information systems, are required.[57]

5.2 New niches and standards

Developing consumers certifications

One of the opportunities for aquaculture production is developing consumers' certification to reap the benefits of niche markets and promote sustainability concern in farmed fish production. This approach, in fact, is based on the setting up of clear standards for producers and an easily recognizable label for consumers. The purpose of eco-labeling is to influence the purchasing decision of consumers, the procurement policies of producers and retailers, and to reward responsible fisheries and aquaculture farms. A range of eco-labeling and certification schemes exist for fish and fisheries products, each with its own specifications, standards, level of transparency and sponsor and can cover different aspects going from environmental aspects or animal welfare to social and economical development projects.

Within aquaculture, there are now many initiatives, among them there is for example GLOBALG.AP, which is a private sector-based business-to-business certification focusing on food safety, animal welfare, environmental protection and social risk assessment standards. This now has certification schemes for shrimp, salmon, pangasius and tilapia and is developing a standard for aquaculture feeds. (Bostock; 2010). Other existing certifications include the IFOAM standards, the International Federation of Organic Agricultural Movements; the standards developed by NATURALAND, a private company.

Another example is the Aquaculture Stewardship Council. In 2009, WWF co-founded with the Dutch Sustainable Trade Initiative (IDH) the Aquaculture Stewardship Council (ASC) a no-profit development organization to manage global standards and certification programs for farmed seafood. The process started in 2004 when a series of policy dialogues were initiated. The 'aquaculture dialogues' were attended by 2000 farmers, retailers, NGOs, scientists and other important stakeholders. The group committed to develop measurable standards for responsible seafood. Up today, standards have been set for salmon, shrimp, tilapia, trout, pangasius, abalone, mussels, clams, oysters, scallops, cobia and seriola. The cultivation of these fish can have a huge impact on natural surroundings and the environment. Their market value and (potential) international commercial value are also high. It was precisely for such reasons that these 12 species were chosen.

ASC works with Accreditation Services International (ASI) to accredit independent certification bodies to audit and certify compliant farms. Fish farmers that pass successfully the audit receive a certificate. In some cases a group of farmers can be the owner of the certificate. The ASC certification, promotes also the full traceability of the products. All companies involved in the supply of ASC certified

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products also have to be ASC certified. [58] WWF is now supporting famers and local communities to adapt production techniques the newly established standards.

Organic Aquaculture

There is unprecedented growth in the demand for certified organic food, and new areas of organic food production, such as seafood, are proving increasingly popular. In reference to the Codex Alimentarius Commission (2011), organic aquaculture refers to the production processes and practices of ecological

production management systems that promote and enhance biodiversity, biological cycles and biological activity (Bergleiter 2003; Bergleiter *et al*., 2009). It is based on minimal use of off-farm inputs and on holistic management practices that restore, maintain and enhance species diversity and ecological harmony (IFOAM EU Group, 2010; Costa-Pierce, 2010). More generally, the primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people. However, details are often unclear to the consumer, e.g. the exclusion of synthetic fertilizers and genetically modified organisms (GMOs) in the production process (Mansfield, 2003, 2004; Hatanaka, 2010). This contribution presents the current status and issues in organic aquaculture production and markets.

'The market for organic seafood products grew enormously in the last 15 years especially in Europe, with Germany, UK, France and Switzerland as leading countries. However an emerging demand is also noticeable among middle classes in transition economies. Part of this demand is met domestically (e.g. carp, brook trout (*Salvelinus fontinalis*) or rainbow trout (*Oncorhynchus mykiss*) in Austria and Germany) or regionally (e.g. salmon, cod and molluscs in northern and western Europe, or seabream, seabass, or even tilapia in countries around the Mediterranean Sea). A large proportion of organically certified aquaculture products are produced in developing countries and processed and shipped to their markets. Organic aquaculture global production saw an increase of 950 percent from 2000 to 2008. Based on the data of 2008, the majority (25000 tonnes/ year) of organic aquaculture production is farmed in Europe, followed by Asia (19 000/year)and Latin America with a total estimated market value of 300 millions of USD in 2009. (Prein *et.al,* 2012)[59]

The standards for organic aquaculture include many requirements on the production system, the feeding, the reproduction and health control. The following table, based on the contribution of Prei *et al*. 2012 presents the main requirements :

General	Closed life cycle in captivity; - It is not permitted a new introduction of a species into a country or location in which it previously did not exist specifically for the purposes of organic agriculture; - Polyculture is the recommended system for organic aquaculture where several species occupy distinctly separated feeding niches within the aquaculture ecosystem; - Ponds and cages are recommended as rearing systems; - The stocking density of culture species is limited; - The use of mechanical aeration is usually banned, while an exception is made only for mechanical mixing and destratification of the water column for a limited number of hours per day with a small number of devices; - Monitoring of effluent quality with the stated goal of avoiding negative impacts on the surrounding environment
Reproduction, Fingerlings and larvae	Indications exist also for the provision of juveniles through controlled conditions. The so to induce a closed cycle and avoid the collection of seeds from the wild; - In the methods to induce spawning , no hormonal sex-inversion is permitted;
Feed	Feed should be certified as organic - In transformation facility full traceability need to be ensured. Organic standards exist for the use of detergents and for pest control substances. - Anesthetization of vertebrates before slaughter is mandatory - Some additives are either restricted or prohibited (e.g. metabisulphites, phosphates, and anticaking agents)
Health	Feed should be certified as organic - In transformation facility full traceability need to be ensured. Organic standards exist for the use of detergents and for pest control substances. - Anesthetization of vertebrates before slaughter is mandatory - Some additives are either restricted or prohibited (e.g. metabisulphites, phosphates, and anticaking agents) *Health* The use of chemicals for sea-lice treatment is not permitted; - Use of antibiotics is not permitted in invertebrates in most private standards, less stringent is the EU regulation to this regard; - For predator control no measure should be taken that could harm the predators. Nets over ponds or cages are recommended for the control of birds.

Source: Prein *et al.* (2012)

Organic aquaculture production represents a good opportunity for producers, it allows them to get a premium price in respect to conventional aquaculture. On the other side it favors animal welfare and human health, limiting the impact on environment. Around 80 organic aquaculture certification standards exist, both public as well as private of which those with the greatest number of certified farms are Naturland, AB France and Bio Suisse. From 2009 in EU it exist the Organic aquaculture implementing rules. Whilst organic aquaculture could dimish the pressure over natural resources of fish farming, some challenges still need to be addressed: the cost of undertaking an adaptation especially for small-scale farmers; the risks that it remains a niche markets; the bottleneck of certified feed. The next paragraph outlines the creation of aquaculture producers'organizations as a strategy to overcome the challenges faced by small-scale famers.

5.3 Collective actions - Aquaculture producers organizations

A large proportion (up to 80 percent) of aquaculture production in many countries in Asia comes from small-scale, family-owned operations (Phillips et al., 2007). However, while this sector is socially and economically important and continues to remain innovative, it faces many constraints and challenges in integrating into modern supply chains (especially for exports) and dealing with the changing market environment. The shift in consumer's preferences towards more healthier food is posing new challenges for small scale aquaculture producers. In fact, the costs and operations associated with obtaining a cretification might be not affordable for and complex for small scale producers.

A joint publication of FAO and WorldFish, drawing on the experience of some projects in Sri Lanka, India, Thailand demonstrated how Farmers Organizations have an important role to play in the sustainable development of the small-scale aquaculture sector. The organization of farmers into FOs can facilitate the certification of groups as opposed to individuals; benefit farmers through economies of scale related to bulk purchasing of inputs and services, collective processing and marketing; support communication, extension training and technology dissemination; and lead to effective management through collective implementation of better management practices (BMPs).[60]

The case of better management practices (BMPs) through cluster management

Cluster management (as the collaborative management of aquaculture production by farmers), has been used as a tool by NACA and other organizations such as FAO to facilitate the implementation of BMPs. Farm cluster consist of famers located in the same local area and often sharing the same water source. Through the collective implementation of BMPs, the NacSA farmers society have succeeded in increasing production levels and the quality of the shrimps, increasing their profits as a result of decreased costs, increased output prices, decreased disease risks and increased market access, even achieving organic certification of two societies. Central to this is the application of BMPs, these are not fixed but constantly reviewed and improved so to meet the changing needs of the culture environment and technology. FOs need to be supported in developing appropriate BMPs for their different commodities and the range of contexts in which they operate BMPs should reduce diseases occurrence and costs of farming, improve growth performance, enhance environmental conditions by minimizing the impact of farming on local environment.

The challenge facing FOs include an effective capacity of involving poorer and subsistence aquaculture farmers. Because of low level of literacy they might be the more risk adverse and incapable of producing reliable surplus that meet market requirement for quality. A market oriented development strategy may not be the most appropriate for this type of famers.

5.4 Recognition of the role of women in aquaculture

Among the opportunities for aquaculture sustainable development there is a better involvement of women. Several studies exist on the involvement of women in fisheries and post-harvest activities in the fishery sector but few studies

focused on women engagement in fish farming. Notwithstanding, a recent expert panel review paper, in the occasion of the Global Conference on Aquaculture in 2010, individuated some of the main contribution of women in fish-farming sector in different countries. For example:

- In *Belize*, most workers involved in processing are women from rural communities where unemployment levels are high and poverty is greatest.

- In *Cuba*, female workers constitute 27 percent of the aquaculture workforce (19 percent are intermediate and higher education technicians; 11 percent have attended higher education institutions).

- In *Jamaica,* about 8–11 percent of fish farmers are women who own and operate fish farms; and in processing plants, women dominate the workforce. (FAO, 2012)

According to FAO, women tend to be excluded from the most profitable markets and enterprises, and from highly paid posts in fish processing factories even though they make up the majority of workers in post-harvest sector. Compared with men, they are often greater losers from increasing market globalization, and they are more vulnerable to poor services and market decline. (FAO, 2012)

Acknowledge the contribution of women in fish farming, addressing the factors and constraints that limit their involvement into the sector is a central question for sustainable fish farming. According to FAO, in fact ' Women's participation as equal and productive partners in the fisheries and aquaculture sector has significant impacts on households' nutrition and living standards.
If fisheries and aquaculture projects generate the data for and potentially, include analyses of, all gender aspects (livelihoods factors, relationships, actions and results), they can contribute to gender equality and promote women's participation as active agents for change in the sector. (FAO, 2012)

One of the practical instrument to do so i sto generate gender disaggregated data for the aquaculture sector. Furthrmore, *gender mapping* is a key tool to make visible and effectively target women. The process aims at highlighting the contribution of women in a certain value chain, mapping the activities in which they are involved, Finally opportunities to upgradre women's position are identified. This approach has already been used in other value chains (see Agri pro focus network) adn could be applied also to aquaculture value chains.

Furthermore 'women should be empowered through gender equity in access to financial, natural, training and market resources. In circumstances where rural men have migrated for work, small-scale aquaculture has proven a suitable livelihood option to reduce the pressure on women. Because postharvest processing and fish trade are feminized occupations, gender equity deserves special attention in fair trade and fish certification schemes. Human capacity development and gender are receiving more attention in rehabilitation efforts to assist survivors from disease and natural disasters'.[61]

6. The way forward

In the medium term, increased output is likely to require expansion in new environments, further intensification and efficiency gains for more sustainable and cost-effective production. Trends towards industrialization and consolidation are strong for some species, especially commodity products that are internationally marketed There is increased private sector involvement in the production and delivery of inputs (seed and feeds) and the manufacture and supply of aquaculture equipment in some countries. However, the small-scale sector is the largest aquaculture producer and mainstay of communities in many parts of the world and needs specific support and capacity-building programmes.

There are measures that policy makers can take for a sustainable development of aquaculture which include providing support to **innovative and technological developments**, ensuring a suitable regulatory framework that captures environmental costs within aquaculture processes, building capacity for monitoring and compliance, and encouraging research on the supply and demand for fish and fish products. There is an urgent need to improve and expand national and international aquaculture statistics collection and reporting schemes.[62] At present, **genetic improvement programs** are underway for a dozen or so widely farmed species, including both marine shrimps and freshwater prawns, common and Indian major carps, tilapias, African and channel catfish, rainbow trout and Atlantic salmon.[63]

The biological and ecosystem arguments for change have been widely expressed, and they have also been reflected in growing consumer awareness and concern for purchasing decisions related to sustainable fisheries. The increasing influence of consumers and markets will contribute to enhanced regulation and improved governance and traceability. However, this bring the risk of marginalisation of those producers wo cannot meet international standards and could contribute to the concentration of production in the hands of wealthier and more skilled farmers. Group certification, as already suggested, is one of the opportunities to reap the benefits of niche markets through collective actions. As effective mean to grant food security and contribute to poverty alleviation, national legal frameworks, sectoral policies and development agencies should strive for greater policy coherence and mutually supportive actions accross different economic, social and enviromental issues. Finally concerning the enviromental impacts of fish farming, Life Cycle Analysis (LCA) and the Ecosystem Approach to Aquaculture (Soto et al. 2009) are new emerging comprehensive approaches that could contribute to the sustainable development growth of the sector.

GLOSSARY[64]

Access

Defined by the rules and social norms that determine the differential ability of people in rural areas to own, control, or otherwise 'claim', or make use of resources such as land and common property. It is also defined by the impact of social relations, for example gender and class, on this ability. Access in addition, refers to the ability to participate in, and derive benefits from, social and public services provided by the state such as education, health services, roads, water supplies and so on.

Adaptation

The process by which individuals (or parts of individuals), populations, or species change in form or function in order to perform better under given or changed environmental conditions. May also be used for the results of this process.

Agreement on Sanitary and Phytosanitary Measures (SPS Agreement)

According to this Agreement, World Trade Organization members have the right to take legitimate measures to protect the life and health of their people from hazards in food, but these measures may not be unjustifiably trade restrictive.

Agroecological zone

A land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use.

Agropisciculture

Combination or alternation of agriculture and freshwater aquaculture.

Alga (pl. algae)

Primitive chlorophyll-containing mainly aquatic eukaryotic organisms lacking true stems and roots and leaves.

Alien species

A species occurring in an area to which it is not native.

Aquaculture

The farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated.

Assets

Resource having commercial or exchange value that is owned by or due an individual, business, institution, or corporation.

Better Management Practices (BMPs)

A series of practices/ recommendations in the area of disease risk factors along, food safety and environmental risks, applied by clusters of aqua-farmers.

Biodiversity

The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems.

Biotic depletion

The volume of wild fish required to support observed aquaculture production.

Cage culture

Culture of stocks in cages. Cages are rearing facilities enclosed on the bottom as well as on the sides by wooden, mesh or net screens. They allows natural water exchange through the lateral sides and in most cases below the cage.

Capacity building

Encompasses the country's human, scientific, technological, organizational, institutional and resource capabilities. A fundamental goal of capacity building is to enhance the ability to evaluate and address the crucial questions related to policy choices and modes of implementation among development options, based on an understanding of environment potentials and limits and of needs perceived by the people of the country concerned.

Certification

It is the process by which a certification body or entity gives written or equivalent assurance that a product, process or service conform to specified requirements. Certification may be, as appropriate, based on a range of audit in the production chain.

Consumer label

Easily recognizable symbol connected to a certification scheme.

Climate

Condition of the atmosphere in a particular region over a long period of time. Climate is a long-term summation of atmospheric elements (e.g. solar radiation, temperature, humidity, frequency and amount of precipitation, atmospheric pressure, speed and direction of wind) and their variations.

Coastal aquaculture

The cultivation of aquatic organisms where the end product is raised in brackish and marine waters; earlier stages of the life cycle of these species may be spent in fresh waters or marine waters.

Coastal area

A geographic entity of land and water affected by the biological and physical processes of both the terrestrial and the marine environments, and defined broadly for the purpose of natural resources management. Coastal area boundaries usually change over time without regard to enabling legislation.

Coastal zone

The band of dry land and adjacent ocean space in which land ecology and use directly affect ocean space ecology and use, and vice versa. For Coastal Zone Management: a geographic entity including both terrestrial and submerged areas of the sea coast, defined legally or administratively for this purpose.

Code of Conduct for Responsible Fisheries (CCRF)

FAO-formulated code, which sets out principles and international standards of behaviour for responsible aquaculture and fisheries practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity.

Code of Practice for Fish and Fishery Products

The draft for the Aquaculture section of this code, prepared by FAO, is presently under review by the Codex Alimentarius Committee on Fish and Fishery Products.

Cost-benefit analysis (CBA)

Assessment of the direct economic and social costs and benefits of a proposed project for the purpose of project or programme selection. The cost-benefit ratio is determined by dividing the projected benefits of the programme by the projected costs. A programme having a high benefit-cost ratio will take priority over others with lower ratios.

Diversity

The number of different species, and their relative abundance, and the number of habitats existing in a particular area. Diversity is a measure of the complexity of an ecosystem, and often an indication of its relative age, measured in terms of the number of different plants and animal species (often called species richness) it contains, their distribution and the degree of genetic variability within each species.

Ecosystem

A natural entity (or a system) with distinct structures and relationships that liaise biotic communities (of plants and animals) to each other and to their abiotic environment. The study of an ecosystem provides a methodological basis for complex synthesis between organisms and their environment.

Ecosystem approach to aquaculture

An ecosystem approach to aquaculture (EAA) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems including their interactions, fl ows and processes and applying an integrated approach to the sector within ecologically and operationally meaningful boundaries.

Environment

All the external or internal factors or conditions supporting or influencing the existence or development of an organism or assemblages of organisms.

Environmental capacity

A property of the environment, defined as its ability to accommodate an activity or rate of activity without unacceptable impact.

Environmental impact

The change in well-being of the ecosystems, that results from a process set in motion or accelerated by man's actions.

Environmental impact assessment (EIA)

A set of activities designed to identify and predict the impacts of a proposed action on the biogeophysical environment and on man's health and wellbeing, and to interpret and communicate information about the impacts, including mitigation measures that are likely to eliminate the risks.
In many countries, organizations planning new projects are required by law to conduct EIA.

Fatty acid

Organic acid composed of carbon, hydrogen and oxygen that combines with glycerol to form fats.

Farmers organization

It is a generic form of association, aiming at providing services to farmers and improving their economic welfare.

Fish

Literally, a cold-blooded lower vertebrate that has fins, gills and scales (usually), and lives in water. Used as a collective term it includes fish, molluscs, crustaceans and any aquatic animal which is harvested.

Fish farm

An enterprise where (fin)fish culture is carried on: an aquaculture production unit either land or water-based, usually consisting of holding facilities (tanks, ponds, raceways, cages), plant (buildings, storage, processing), service equipment and stock.

Fish oil

Oil extracted from total fi sh body or from fi sh waste. Fish oils are used in the manufacture of fi sh feeds,

edible fats and industrial products.

Fishmeal

Protein-rich meal derived from processing (boiling, pressing, drying, grinding) whole fi sh (usually small pelagic fi sh or bycatch) as well as residues and by-products from fi sh processing plants (fish offal). Used mainly as agriculture feeds for domestic livestock (poultry, pigs, cattle, etc.) and as aquaculture feeds for carnivorous aquatic species.
It must contain not more than 10 percent moisture. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the brand name, provided that in no case must the salt content of this product exceed 7 percent.

Food security

Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Gender mapping

Process aiming at individuate the activities in which women are involved in a certain value chain.

Inland aquaculture

Aquaculture that takes place in freshwater.

Intensification

The increase of production in an aquacultural or agricultural system through increasing the stock or planting density (and expected production) in the existing water or wetland area.

Livelihood security

Refers to secure rights, physical safety and reliable access to resources, food and cash to meet basic needs and to support well-being. Livelihood security is basic to well-being.

Malnutrition

An abnormal physiological condition caused by deficiencies, excesses or imbalances in energy, protein and/or other nutrients.

Natural capital

The natural resource stocks from which resource flows useful to livelihoods can be derived (land, water, wildlife, environmental services).

Nutrition security

It is achieved when secure access to appropriately nutritious food is

coupled with a sanitary environment, adequate health services and care, to ensure a healthy and active life for all household members.

Organic aquaculture

The production of fish according to certain specific standards that aim at reducing the environmental impact of fish production on the surrounding ecosystem.

Pen culture

Culture of stocks in pens. Pen is a fenced, netted structure fi xed to the bottom substrate and allowing free water exchange; in the intertidal zone, it may be solid-walled; the bottom of the structure, however, is always formed by the natural bottom of the water body where it is built; usually coastal e.g. in shallow lagoons, but also inland e.g. in lakes, reservoirs. A pen generally encloses a relatively large volume of water.

Pisciculture

The breeding, rearing, conservation, etc. of finfish by means that supplement or replace those normally available in nature.

Pollution

The introduction by human activities, directly or indirectly, of substances or energy into the environment resulting in deleterious effects on living organisms.

Pond

Relatively shallow and usually small body of still water or with a low refreshment rate, most frequently artificially formed, but can also apply to a natural pool, tarn, mere or small lake.

Recirculating system

A closed or partially closed system employed in aquaculture production where the effluent water from the system is treated to enable its reuse.

Stock

In fisheries: a quantity of fish considered in a given situation.

Sustainable development

Management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations. Such sustainable development conserves (land), water, plants and (animal) genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable.

Trash fish

Small fish species, damaged catch and juvenile fish are sometimes referred to as ‘trash fi sh’ because of its low market value. Usually part of a (shrimp) trawler’s bycatch. Often it is discarded at sea although an increasing proportion is used as human food or as feed in aquaculture and livestock feed.

Undernutrition

It happens is when the body contains lower than normal amounts of one or more nutrients i.e. deficiencies in macronutrients (carbohydrates, proteins) and/or micronutrients (amino acids, vitamins, minerals), such that stunting, wasting and illness will occur.

Zoonotic

Pertaining to a zoonosis: a disease that can be transmitted from animals to people or, more specifically, a disease that normally exists in animals but that can infect humans.

ACRONYMS

ASC	Aquaculture Stewardship Council
BMPs	Better Management Practices
CCA	Climate change adaptation
CCRF	Code of Conduct for Responsible Fisheries (from FAO)
COFI	FAO Committee on Fisheries
COP	Code of Practice
CPUE	Catch per unit of effort
DRM	Disaster risk management
DRR	Disaster risk reduction
EAA	Ecosystem approach to aquaculture
EAF	Ecosystem approach to fisheries
EC	European Commission
EEZ	Exclusive economic zone
EIFAAC	European Inland Fisheries and Aquaculture Advisory Commission
EIFAC	European Inland Fishery Advisory Commission
FOs	Farmers Organisations
GIS	Geographic Information System
IAA	Integrated aquaculture/agriculture
IFOAM	International Organization of Organic Agriculture Movements
IMO	International Maritime Organization
ILO	International Labour Organization
IUU	Illegal, unreported and unregulated fishing
LCA	Life Cycle Analysis
LDC	Least-developed country
LIFDC	Low-income food-deficit country

MPA	Marine protected area
NACA	Network of Aquaculture Centres in Asia-Pacific
OECD	Organisation for Economic Co-operation and Development
OIE	World Organisation for Animal Health
RFB	Regional fishery body
RFMO	Regional fisheries management organization
R&D	Research and development
SARNISSA	Sustainable Aquaculture Research Networks for Sub-Saharan Africa
SIS	Small indigenous fish species
SPC	Secretariat of the Pacific Community
WHO	World Health Organization
WTO	World Trade Organization

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