Addressing aquaculture-fisheries interactions through the implementation of the ecosystem approach to aquaculture (EAA)

Expert Panel Review 3.2

Doris Soto[1] (*), Patrick White[2], Tim Dempster[3], Sena De Silva[4], Alejandro Flores[5], Yannis Karakassis[6], Gunnar Knapp[7], Javier Martinez[8], Weimin Miao[9], Yvonne Sadovy[10], Eva Thorstad[11] and Ronald Wiefels[12]

[1] Doris Soto, FAO of the UN, Italy. E-mail: doris.soto@fao.org
[2] Patrick White, Akvaplan-NIVA, France. E-mail: patrick.white@wanadoo.fr
[3] Sena De Silva, Deakin University, Victoria, Australia. E-mail: sena.desilva@deakin.edu.au
[4] Tim Demster, Centre for Research-based Innovation in Aquaculture Technology (CREATE), Trondheim, Norway. E-mail: tim.dempster@sintef.org
[5] Alejandro Flores, Regional Office for Latin America and the Caribbean, Santiago, Chile. E-mail: alejandro.flores@fao.org
[6] Yannis Karakassis, University of Crete, Greece. E-mail: karakassis@biology.uoc.gr
[7] Gunnar Knnap, University of Alaska Anchorage, United States of America. E-mail: gunnar.knapp@gmail.com; gunnar.knapp@uaa.alaska.edu
[8] Javier Martinez-Cordero, Centro de Investigación en Alimentación y Desarrollo (CIAD), Sinaloa. México. E-mail: jav_hot@hotmail.com; cordero@ciad.mx
[9] Weimin Miao, FAO Office RAP, Bangkok, Thailand. E-mail: weimin.miao@fao.org; fao-rap@fao.org
[10] Yvonne Sadovy, The University of Hong Kong, China. E-mail: yjsadovy@hkucc.hku.hk
[11] Eva Thorstad, Norwegian Institute for Nature Research (NINA), Trondheim, Norway. E-mail: eva.thorstad@nina.no
[12] Roland Wiefels, INFOPESCA, Montevideo, Uruguay. E-mail: roland.wiefels@infopesca.org

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Abstract

This review addresses how the ecosystem approach to aquaculture (EAA) can optimize aquaculture-fisheries interactions considering different spatial scales from farm, aquaculture zone and watershed through to the global market. Aquaculture and fisheries are closely related subsectors with frequent interactions, largely due to the sharing of common ecosystems and natural

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* Corresponding author: Doris.Soto@fao.org

resources. Interactions are also born from the flow of biomass from fisheries to aquaculture through fish-based feeds (e.g. fishmeal, fish oil and trashfish), through the collection of wild seed and brookstock, and genetic resources and biomass transfer from aquaculture to fisheries through culture-based fisheries (CBF) and escapees. Negative effects include modification of habitats affecting fisheries resources and activities (e.g. mangrove clearing for shrimp ponds, seabed disturbances through anchoring of aquaculture cages or pens, damage to seagrasses, alteration to reproductive habitats, biodiversity loss). Eutrophication of waterbodies due to excess nutrient release leading to anoxia and fish mortality can also impact negatively on biodiversity and wild fish stocks. Release of diseases and chemicals also imposes some threats on fisheries.

Yet there could be beneficial impacts; for example, aquaculture is increasingly contributing to capture fisheries through CBF and could contribute to restore overfished stocks. Aquaculture can offer alternative livelihoods to fisherfolk, providing increased opportunity to them and also to their families, and especially to women. Aquaculture-increased production and marketing can also enhance and indirectly improve processing and market access to similar fishery products.

The ecosystem approach to aquaculture (EAA) is a strategy for the management of the sector that emphasizes intersectoral complementarities by taking into account the interactions between all the activities within ecologically meaningful boundaries and acknowledging the multiple services provided by ecosystems. The main objective of this review is to understand the status of aquaculture-fisheries interactions associated with the biological, technological, social, economic, environmental, policy, legal and other aspects of aquaculture development and to analyze how these interactions are or could be addressed with an EAA. Therefore, the review involves aspects of scoping, identification of issues, prioritizing, devising management tools and plans for minimizing negative effects and optimizing positive ones within the context of social-ecological resilience, at different relevant geographical scales.

Many of the management measures suggested in this review must involve not only EAA but also an ecosystem approach to fisheries (EAF), especially to deal with issues such as fishery of wild seed and the management of fisheries to produce fishmeal/oil for pelleted feeds or for direct feeding with wet fish.

The implementation of EAA and EAF should help to overcome the sectoral and intergovernmental fragmentation of resource management efforts and assist in the development of institutional mechanisms and private-sector arrangements for effective coordination among various sectors active in ecosystems in which aquaculture and fisheries operate and between the various levels of government. Ecosystem-based management involves a transition from traditional sectoral planning and decision-making to the application of a more holistic approach to integrated natural resource management in an adaptive manner.

KEY WORDS: *Aquaculture-fisheries interactions, Ecosystem approach to aquaculture, Culture-based fisheries, Food security, Integrated management, Stakeholder participation.*

Introduction

Background

Aquaculture and fisheries[1] are subsectoral activities that often can depend on the same natural resources and share the same ecosystem and spatial boundaries, even global boundaries when aquaculture consumes fishmeal from far away fisheries. Both sectors can impose external costs or benefits on each other and compete in downstream markets. They have close and complicated interactions with each other directly or indirectly, as the result of environmental changes caused by one or the other. Effective implementation of an ecosystem approach to fisheries (EAF) (FAO, 2003)/ecosystem approach to aquaculture (EAA) (FAO, 2009) will require a good understanding of such interactions, mutual impacts and potential synergies.

The two subsectors have interacted closely ever since aquaculture came into being. In ancient times, fish farming originated from the collection of wild seed for further fattening and growth in human-made enclosures; thus, aquaculture used to rely completely on fisheries resources, depending on seed supply from natural stocks. Along with the progress in aquaculture-related technology such as controlled seed production in hatcheries, the dependency on wild seed has declined; and we are moving towards a phase where aquaculture can potentially produce seed not only to supply culture production but also to stock into wild resources, usually known as culture-based fisheries (CBF) (see Lorenzen *et al.,* 2000; Lovatelli and Holthus, 2008). Thus, wild-caught seed as an output from a capture fishery can be considered as an input to aquaculture. Similarly, seed output from a hatchery when used for stock enhancement in CBF can be considered as an input to capture fishery.

Another clear interaction and strong aquaculture dependency on fishery is the use of pelagic resources for the production of fishmeal and fish oil and the use of bycatch or trash fish as feeds for aquaculture. Indeed, aquaculture has been criticized for putting additional pressure on pelagic fishery resources for the production of pelleted feeds (Tacon *et al*., 2012).

Aquaculture can also negatively affect fisheries through the disruption of natural habitats and sensitive ecosystems for the construction of aquaculture farms. The excessive nutrient discharge from farms that could cause eutrophication (Gowen, 1994), the escape of farmed organisms (Thorstad *et al.,* 2008) and

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[1] In this review, farmed fish and fish from capture fisheries include all aquatic organisms that are considered in capture fisheries and aquaculture (e.g. fish, crustaceans, molluscs, etc.).

the use of chemicals and fertilizers (Soto *et al*., 2008) can all negatively affect fisheries. However, aquaculture can affect fisheries in positive ways; for example, by providing alternative livelihoods to fisherfolk, including the postharvest processing and marketing of aquaculture products and also by enhancing fisheries (including overharvested stocks) through hatchery-produced seed. This review describes the likely interactions in more detail and provides a management perspective with an ecosystem approach

The EAF and EAA management approach ensures sustainable fish production and nutritional benefits from both subsectors and facilitates the integration between them. Such integration takes into consideration the multiple uses of common aquatic resources and the full set of ecosystem services and functions they provide, as well as the economic, social and cultural values that people attach to these services.

Objectives

The main objectives of this thematic review are to present an overview of the aquaculture-fisheries interactions and to provide ways to minimize those that are negative while optimizing positive ones, using an ecosystem approach to the management of both sectors but focusing on aquaculture. The process to achieve these goals is also designed to promote greater interaction and wider participation during the review process, as well as involvement of a wide cross-section of different stakeholders in aquaculture development. An attempt is also made to assess the extent to which the aquaculture-fisheries interactions have been recognized and managed, thereby contributing to the implementation of the Bangkok Declaration (NACA/FAO, 2001).

This review focuses more on the effects of aquaculture on fisheries rather than on the effects of fisheries on aquaculture, since the latter are mostly positive (feeds, seeds, etc.). We thus concentrate on minimizing aquaculture's negative impacts and maximizing its benefits (e.g. through CBF).

General scenarios for the sector

The current fisheries scenario

Global capture fisheries production in 2008 was about 92 million tonnes, with an estimated first-sale value of USD91.2 billion, comprising about 82 million tonnes from marine waters and a record 10 million tonnes from inland waters (FAO, 2010a). The world's catches have been more or less stagnant or even declining during the past decade. Many fish stocks are widely reported to be in a state of serious decline. The Food and Agriculture Organization of the United Nations (FAO) reports that nearly 80 percent of world fish stocks are fully or over exploited (FAO, 2010a). This situation may pose a threat to aquaculture, including limitations to seed supply but mainly through the production of fishery-based feeds. On the other hand, the current fisheries situation increases the demands and expectations on aquaculture as fish supplier for the next decades and future generations. The situation also offers an opportunity for aquaculture to supply and enhance fisheries through the provision of hatchery-produced seed.

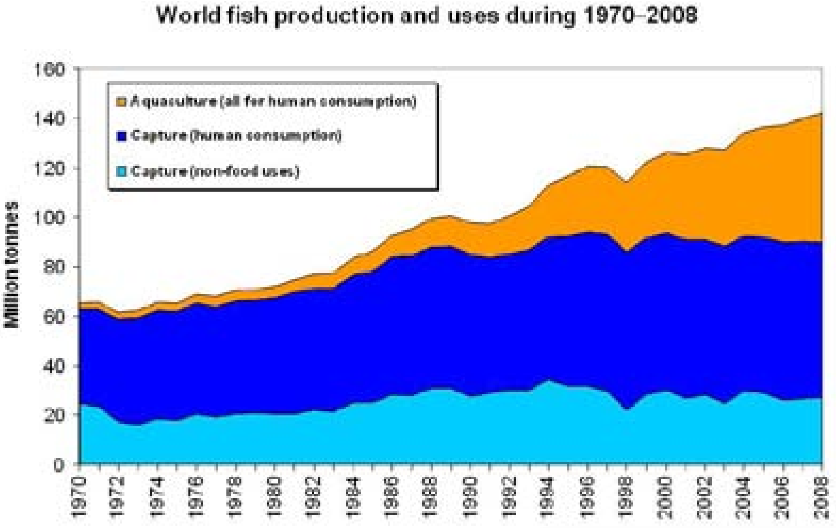
Further growth of aquaculture

Aquaculture continues to be the fastest-growing animal food-producing sector and to outpace population growth, with per capita supply from aquaculture increasing from 0.7 kg in 1970 to 7.8 kg in 2008, an average annual growth rate of 8.3 percent (FAO, 2010a). Considering the fisheries scenario described above, aquaculture will most likely overtake capture fisheries as a source of food fish within the present decade. From a production of less than 1 million tonnes per year in the early 1950s, production in 2008 was reported to be 52.5 million tonnes with a value of USD78.8 billion, representing an annual growth rate of nearly 7 percent.

World aquaculture, including CBA, is heavily dominated by the Asia-Pacific region, which accounts for 89 percent of production in terms of quantity and 78.7 percent in terms of value. This dominance is mainly due to China's enormous production, which accounts for 62.3 percent of global production in terms of quantity and 49 percent of global value.

Figure 1 shows the trends in capture fisheries (both for direct consumption and other uses) and aquaculture. Part of the non-food uses (i.e. fishmeal and fish oil) is being transformed into aquaculture, although as seen in the figure, aquaculture increase does not seem correlated to fishmeal fisheries.

FIGURE 1
World fish production from capture fisheries (food and non-food) and aquaculture. About 75 percent of non-food uses are for reduction (fishmeal, fish oil)



Source: Fishstat plus (FAO, 2010c).

Implementing the EAA

What is the EAA and why is it needed?

Aquaculture should try to not compromise fisheries, but should seek to complement it by providing a net increase of fish output and food security as the global population keeps increasing and more food fish is needed. A sustainable increment of aquaculture output therefore requires an ecosystem perspective. There is an increasing recognition of the need to move towards more holistic fisheries and aquaculture management planning frameworks. However, the practical approach and application of ecosystem-based planning and management remains challenged by a poor understanding of this approach and the need for considerable policy reforms (Soto *et al.,* 2008).

Countries worldwide are also attempting to implement a diverse array of aquaculture regulations to control inadequate development of the sector. Yet some constraints persist that do not allow aquaculture and fisheries interactions to be adequately addressed. These often include:

- lack of awareness and understanding of such interactions in the context of ecosystem processes;
- lack of appropriate connection between ecological and social processes;
- lack of consideration of relevant boundaries and a multiple-scales approach, when appropriate; and
- lack of integrated multisectoral planning and management involving aquaculture and fisheries.

The FAO *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995) provides a global framework for responsible fisheries (including aquaculture). Nonetheless, member countries, fisheries organizations and fisheries stakeholders require a practical framework to implement the recommendations of the CCRF. The ecosystem approach to management of fisheries (EAF) and aquaculture (EAA) provides such a practical implementation framework where the objectives of responsible and sustainable fisheries and aquaculture can be translated into practical implementation at the national and local levels. This review will focus mainly on management from the aquaculture perspective.

> *"An Ecosystem Approach to Aquaculture is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems"* (FAO, 2010b).

The EAA builds on the conceptual frameworks of the ecosystem approach as set by the Convention on Biodiversity (CBD) (UNCBD, 1992) and the ecosystem approach to fisheries (EAF) (FAO, 2003, 2009), as well as initiatives related to planning and management for sustainable coastal aquaculture development (e.g. GESAMP, 2001).

As a strategy to ensure that aquaculture contributes positively to sustainable development, the EAA should be guided by three main interlinked principles (FAO, 2010b):

Principle 1: Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society.

Principle 2: Aquaculture should improve human well-being and equity for all relevant stakeholders.[2]

Principle 3: Aquaculture should be developed in the context of other sectors, policies and goals.

The EAA as a “strategy” should be the means to achieve or fulfil a higher policy level that reflects relevant national, regional and international development goals and agreements. Two elements are fundamental throughout the process: i) to collect and use all the best available information and ii) to have a broad stakeholder participation.

To implement the strategy successfully, it is necessary to translate the relevant policy goals into operational objectives and actions. The high-level policy should ensure or facilitate sustainable net fish production for food and livelihoods” (Figure 2).

FIGURE 2
The EAA Planning and implementation process

Source: AFPIC (2009), FAO (2010b).

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[2] Especially the local communities where aquaculture takes place.

Implementation of the EAA has several steps, similar to those in the EAF. The first step, the scoping (Figure 2), requires defining the spatial boundaries where aquaculture and its effects take place. The definition of the relevant boundaries allows the identification of the relevant issues and stakeholders and leads to operational objectives and the development of the implementation plan.

In this review, we start by describing the different steps of the process and then explore in more detail the key issues in aquaculture-fisheries interactions to finally address some of the management measures within an ecosystem approach.

Scoping: defining ecosystem boundaries and the relevant stakeholders

The implementation of an EAA must consider the interactions between aquaculture and all other sectors and users of the watersheds and coastal ecosystems. However, this review will focus only on the interaction between aquaculture and fisheries. The following sections describe the scoping process and some of the aquaculture-fishery issues at each scale.

Ecosystem boundaries and spatial scales

The definition of the relevant ecosystem boundaries is a necessary exercise to identify stakeholders, to address issues and to implement the EAA (Soto *et al.*, 2008). It is also needed to decide whether the planning and implementation of the strategy will cover the whole aquaculture sector of a country or region, or (more typically) will address an aquaculture system or aquaculture area in a country/subregion. In most cases, aquaculture, fisheries and other sectors share an ecosystem with regard to services and space. The most typical scales are: i) the farm, ii) the watershed, waterbody or coastal zone, and iii) the national, regional or global area.

The individual farm is easy to locate and identify, and local effects are often relatively easy to assess. Although it may seem less relevant or meaningful to talk about interactions at this scale, there are cases of large farms negatively affecting fisheries; for example, large shrimp farms built within mangrove areas modify the habitat, which negatively impacts on fisheries and the generation of other ecosystem services, and may also restrict access to local small-scale fisheries. Escapees and diseases originating from a farm can be prevented and/or controlled at the farm scale, although their effects usually occur at the next spatial scale, the watershed, waterbody or coastal zone. Stakeholders are the farmers and workers.

The second scale, that of the watershed, waterbody or coastal zone, includes a cluster of farms that share a common area of water and that need coordinated management. Most relevant aquaculture-fisheries interactions take place at this scale. For example, the eutrophication effect of many small farms on a lake will affect wild fisheries in that lake by triggering anoxic episodes, thus resulting in fish kills. Clearance of mangrove areas for culture operations may reduce settlement habitat for local fisheries. Stock enhancement usually takes place at this level as well, and the introduced seed and larvae can affect other species and local fisheries. Stakeholders and relevant institutions include: clusters of farms or farmers, individuals involved in postharvest processing and marketing, watershed management bodies, fishers and fisheries institutions and local communities.

The global scale refers to the global industry for certain commodity products (e.g. salmon, shrimp, catfish) and also to global issues such as production, trade of fishmeal and fish oil for feeds, trade of aquaculture products, certification, technological advances, research and education of global relevance. Of particular importance is the world supply of fishmeal as a key ingredient of animal feeds, in particular aquaculture feeds. Most relevant at this scale are the consumers and institutions involved in global trade and global governance.

Identification of issues

Identification of issues where aquaculture affects fisheries can be facilitated by the development of component trees (FAO, 2003) that cover each of the three key areas of EAF and EAA, and these are; human well-being, ecological well-being and ability to achieve (Figure 3). This method also helps to identify issues by structuring the issues into related groups, thus determining their priority and developing management objectives and strategies. The generic trees presented below provide a starting point to help the process of identifying which issues are relevant to the fishery and aquaculture systems being assessed.

Aquaculture is strongly linked to fisheries and affects the latter sector in many ways, both negatively and positively, that can be identified through the production process, inputs/resource use and outputs (Figure 4). Aquaculture

FIGURE 3
Assessment of ecological, socio-economic and "ability to achieve" issues

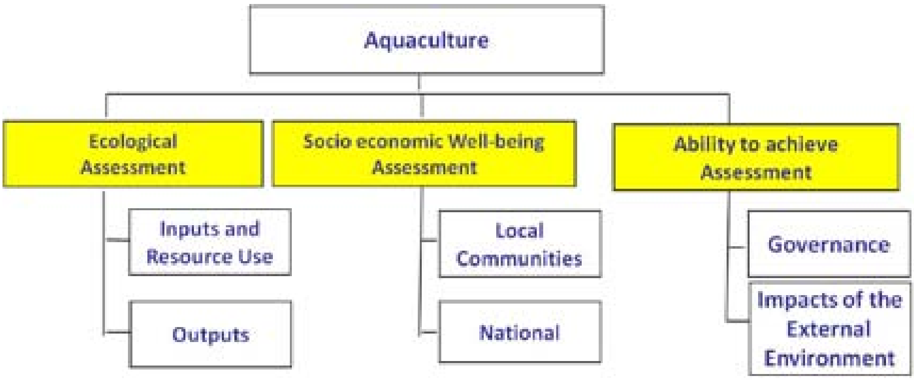
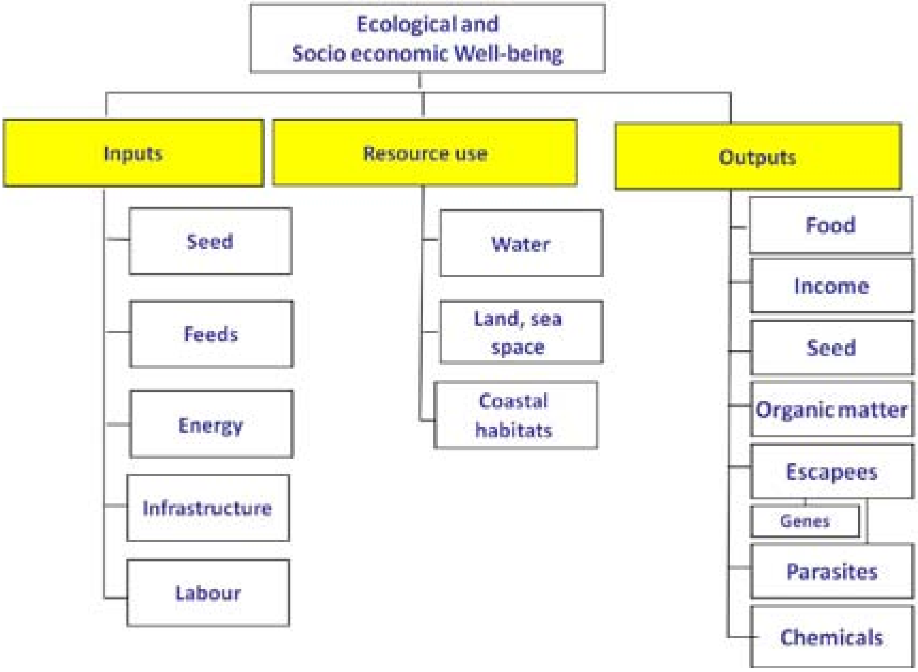


FIGURE 4
Schematic tree to identify issues related with different parts of the aquaculture production process



Source: APFIC (2009).

as a production process requires inputs such as seed and feeds, and requires land, water and coastal space. It produces expected outputs such as biomass, together with unwanted outputs such as excess nutrients, organic matter, chemicals and escapees (Figure 4). Throughout these processes, there are interactions with fisheries. Usually ecological issues (e.g. effects on the resources) have related socio-economic issues (often affecting the fisheries) and ecological and socio-economic issues almost always have a root cause in the governance or ability to achieve.

A further disaggregation of some of the issues related to inputs, resource use and outputs can be seen in Figures 5A and B.

Some governance issues are shown in Figure 6. External drivers should also be considered under “ability to achieve” for example, catastrophic events, climate change, international markets, etc. These can in turn modify the aquaculture effect on the fisheries sector (see Figure 6).

FIGURE 5
Potential effects of aquaculture on fisheries related to inputs (A) and outputs (B). Sign beside indicates negative or positive effect

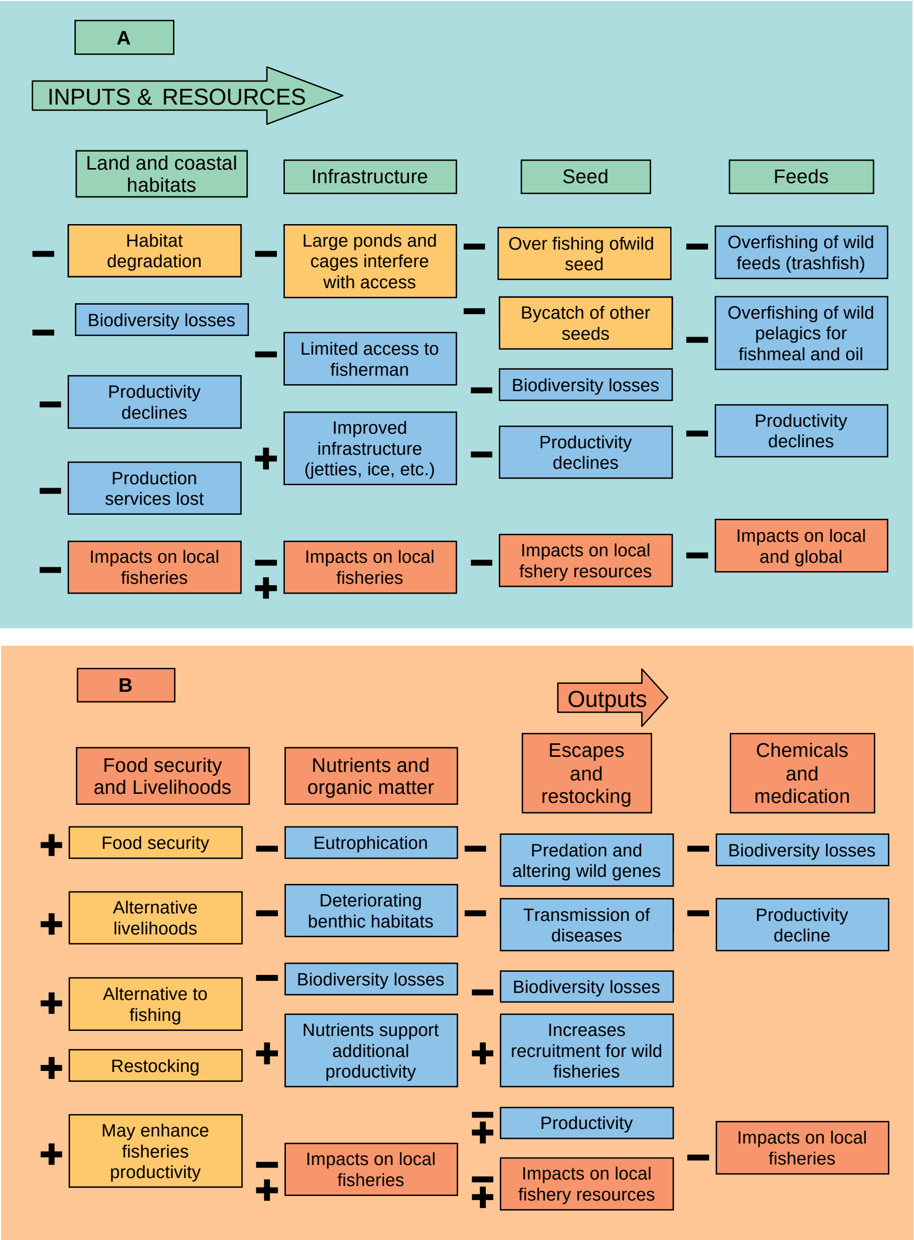
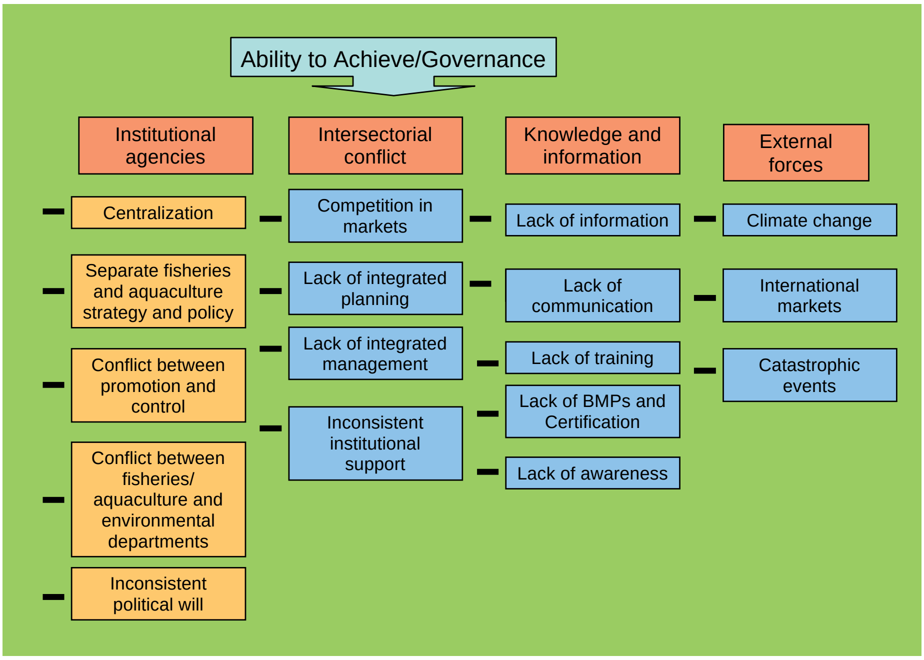


FIGURE 6

Governance issues in the interaction between fisheries and aquaculture



Main issues during the past decade and management measures within EAA

In the following sections, we describe the main interactions between aquaculture and fisheries, focusing mainly on aquaculture's effects on fisheries (issues). We provide examples and case studies and also summary tables where we include potential solutions following an EAA development. Solutions should consist of well-planned management measures that take in account the three guiding principles, that is, the ecological carrying capacity, the social equity and economic benefits and the need to integrate aquaculture with other users of the shared ecosystems and resources. Management measures have to respond to the priorities set by the overarching policy goal and the operational objectives. Diverse management measures are explored in more detail in the sections that follow.

Issues related to resource use and habitat modification by aquaculture

Capture of seed, juveniles and broodstock

Capture-based aquaculture (CBA) is a globally significant activity that can involve the capture of wild individuals, either as broodstock to produce eggs, or as early life stages for on-growing under controlled conditions. These early stages, generically referred to as "seed", vary from eggs to postlarvae through to late-stage juveniles and even small adults. CBA is distinct from hatchery-based aquaculture (HBA) in that animals are sourced from the wild rather than from hatcheries. CBA is practiced on a diverse range of freshwater and marine species of fish and invertebrates and is a highly significant economic and social activity that has important environmental, including ecosystem, implications. In general, these include over-harvesting of the younger stages of a population, with negative consequences for the sustainability of that population and for related food webs and nutrient cycling (see Box 1).

At least 70 species are included in CBA operations, and these fall mainly into four taxonomic groups: molluscs, crustaceans, echinoderms and finfish. Species involved include such commodities as oysters, bluefin tuna, shrimps, lobster, cod, carps, groupers, seahorses, mussels, crabs, eels, mullets and sea cucumbers (Lovatelli and Holthus, 2008; Sadovy de Mitcheson and Liu, 2008).

This type of aquaculture is practiced on high-value marine finfish species such as tuna which require high protein diets and sturdy culture facilities. However, CBA is also practiced with low-value fish species that are sometimes farmed in small ponds or using inexpensive farming systems with minimum inputs, such is the case of some native freshwater fish in the Amazonian basin (Sadovy de Mitcheson and Liu, 2008). CBA is practiced extensively with bivalves such as mussels that also require minimum inputs and have seed that is generally easily collected.

Although CBA is the oldest type of aquaculture, its current relevance has not been well documented despite the scale of operations involved. FAO, for example, has no database that specifically identifies the global production due to CBA. However, it is estimated that CBA practices provide about 20 percent of the total world marine aquaculture production, while many freshwater species are also cultured, at least in part, from fry caught from the wild (Lovatelli and Holthus, 2008). The reasons for such extensive use of wild animals in culture operations include the inability to raise a wide range of species in hatcheries, supply from hatcheries that does not meet demand or is not of preferred quality, and wild supply that is cheaper or more readily available.

Examples of the different types of CBA include: broodstock collection (e.g. shrimp and groupers), fry collection (e.g. eels, milkfish, shrimp), juvenile collection (e.g. groupers, tuna) and adult collection (e.g. bluefin tuna) to fatten and improve meat quality in short-term holding, as well as for broodstock (Sadovy de Mitcheson and Liu, 2008).

The extent and relative use of wild seed in CBA should decline as the technology for hatchery-produced seed becomes more widespread. Table 1 provides a global expert coarse estimate of the proportion of seed/juveniles obtained from wild or hatchery.

BOX 1. Capture of wild seed: the case of shrimp in Asia and in Latin America

Despite the fast improvements in the hatchery production of postlarvae, shrimp farming in some countries and remote areas still relies on natural seed. Many small-scale shrimp farmers of Latin America continue to use wild-caught postlarvae to stock their production ponds. Also, adult shrimp are routinely captured as broodstock in many parts of the region without having adequate scientific information that supports the level of impact on wild populations. The collection of postlarvae has certainly impacted the wild populations of both the targeted species and the species that are caught incidentally. For example, in Nicaragua, the collection of postlarvae in the wild is claimed to be a major factor responsible for the reduction of shrimp fisheries and other fisheries. Larvae of other crustaceans, fish and other animals of a wide diversity are caught and discarded as bycatch during the shrimp postlarvae collection process, thus affecting non-targeted populations as well. However, wild shrimp postlarvae continue to be utilized because of their apparent hardiness and relatively low price, although the threat of disease is increasingly reducing such a practice. Additionally, it is well known that the use of wild stock, either for breeding or direct culture and their uncontrolled movement by farmers conveys risks of disease and species introductions.

A different situation is being experienced in Asia, which produces about 80 percent of the world's farmed shrimp (*Fishstat plus*, FAO, 2010c). Until the beginning of the current decade, the region relied primarily on the wild-caught *Penaeus monodon* seed and broodstock; however this species is quickly being replaced by the exotic *Litopenaeus vannamei,* introduced from Latin America. Currently the hatcheries in the region produce hundreds of billions of postlarvae per year of this species, and this is considered a big step forward for sustainable aquaculture. Nevertheless, the other 30 percent of farmed Asian shrimp, mostly *P. monodon*, still depends upon wild shrimp populations to provide seed and most of the broodstock requirement. It is just as susceptible to fluctuations in the availability of wild resources as any capture fishery activity. Therefore, the conservation of wild genetic resources is invaluable to shrimp farming.

TABLE 1
Main species groups used in CBA and global estimated* proportion of origin for the seed. (Wild = W; mostly wild (MW = <10% hatchery seed); HH = about half from hatcheries; MH = mostly from hatcheries)

Species group	Larvae obtained from
Bluefin tuna	W
Eels	W
Oysters	MW
Mussels	MW
Lobster	MW
Seahorses	MW
Mullet	MW
Cod	HH
Grouper	HH
Sea cucumber	HH
Shrimp	MH
Tilapia	MH^2
Carps	MH

* *Source:* FAO fisheries and aquaculture internal database.

The positive and negative issues related to fisheries inputs to aquaculture and possible management solutions addressing negative impacts within an EAA are given in Table 2.

TABLE 2
Issues related to live inputs to aquaculture and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
- Mass capture of wild seed, juveniles or broodstock can lead to negative recruitment of wild fisheries (-) - Bycatch of other species along with target species (-) can lead to biodiversity loss, potentially affecting wild fisheries - Destructive fishing practice for collection of wild seed or broodstock (-) can damage fisheries habitat - Capture of wild seed for aquaculture provides livelihoods to thousands of poor fishers and fisheries communities (+)	- EAF management measures - Monitoring and controlling fisheries pressure for seed and fry collection - Definition of quotas and licences for wild seed/ juvenile/subadult and adult collection - Review of fishing methods to reduce bycatch and habitat damage - Provide training and other incentives to use more friendly methods - Provide alternative livelihoods to fishers - Make hatchery seed more readily available and less expensive

Fisheries reduction to fishmeal and fish oil for aquaculture feeds

Fishmeal and fish oil are important protein and energy sources for fish farming feeds. Of the world's total catch of fish, approximately 22 per cent goes to produce fishmeal and fish oil (*Fishstat plus,* FAO, 2010c; Tacon *et al.*, 2011; also see Figure 1). Fishing activities in the Southeast Pacific and Northeast Atlantic are the main sources of the world's production of fishmeal and fish oil. Small pelagic fishes are heavily used as fish feed. These fish are generally the only commercially viable source of long chain omega-3 fatty acids essential to diets for carnivorous farmed fish, such as salmon and tuna, which have high market value and are typically sold in wealthy, developed countries.

Together with aquaculture's rapid development, aquaculture's share of global fishmeal and fish oil consumption has increased. In 2007, the aquaculture sector consumed about 3.8 million tonnes of fishmeal (68.4 percent of total global production) and 0.8 million tonnes of fish oil (81 percent of global production) (Tacon *et al.* 2011).

On the other hand, the ratio of wild fish input via industrial feeds to total farmed fish output has fallen by more than one-third from 1.04 in 1995 to 0.63 in 2007 (Naylor *et al*., 2009). Such decline underscores the expanding volume of omnivorous fish produced on farms and market pressures to reduce fishmeal and fish oil levels in aquafeeds. Nonetheless, serious challenges remain for lowering the percentage inclusion rate and total quantity of fishmeal and fish oil inputs in feeds and for alleviating pressure on fisheries for aquaculture feed over time. There are also challenges and criticisms to the calculations of fish-in/fish-out ratios (Jackson, 2009) and recommendations to consider efficiency of the reduction in terms of protein, nutrients and energy (Kaushik and Troell, 2010).

One of the main problems is that the scale of this interaction is at the global level, and therefore a challenge and opportunity for EAA is to address the issue with the stakeholders at the local level and with consumers at a broader scale.

Use of low-value fish as feed

Marine finfish aquaculture in Asia has been developing rapidly at around 10 percent per annum, contributed 4 percent of the global finfish production annually over the last decade, and is the fastest growing protein-producing subsector in Asia. However, the subsector is heavily dependent on "trash fish" or "low-value fish",[3] almost always as the only food source of the cultured stocks. It has been estimated that the marine aquaculture sector in China in 2000 consumed about 4 million tonnes of low-value fish (D'Abramo, Mai and Deng, 2002). Demand for trash fish or low-value fish is likely to increase unless viable alternatives are made available and used, and unless the efficacy of use of these feed sources is improved (Edwards, Tuan and Allan, 2004). In the Asian region, one of the fastest growing mariculture commodities is grouper, about six species in all, and in 2005, grouper culture accounted for about 65 000 tonnes and is expected to grow further. The total use of low-value fish by the aquaculture industry in Viet Nam by the year 2013 could be about one million tonnes (De Silva and Hasan, 2007). This is a contentious issue from a resource use view point, reflected in the very high fish to fish conversion rates

The issues related to the use of fish as aquaculture feed and possible management solutions addressing the negative impacts within an EAA are given in Table 3.

TABLE 3
Issues related to the use of fish as aquaculture feed and management solutions within an ecosystem approach to fisheries (EAF) and aquaculture (EAA)

Impacts and sign of effects (- or +)	Possible management solutions for negative effects

- Increased pressure on pelagic fisheries resources to provide fishmeal and fish oil (-)
- Increased fishing pressure on low-value species for feeding directly to higher-value species (-)
- Job and income generation in fishmeal-producing countries (+)
- Provides export earnings to fishmeal-producing countries (+)
- "Low value" fish taken out of the market chain for hungry and poor (-)
- Price of low-value fish rises due to demand from aquaculture, making them less accessible to the poor and hungry (-)
- Provides livelihoods for small-scale fishermen and fisheries communities who provide low-value species to cage farmers (+)
	- Implement sustainable management of fishmeal/ fish oil/trash fish fisheries (follow EAF)
	  - Monitoring and controlling fisheries
	  - Definition of quotas and licences
	  - Fisheries certification and ecolabeling
	  - Provide alternative livelihoods to fisheries for "feeds"
	  - Perform holistic studies, including on the environmental, social and economic aspects of fisheries and aquaculture and their interaction at local levels, when appropriate
	- Facilitate access to pelleted feeds
	- Increase effort to find substitute ingredients
	- Discourage the culture of top carnivore species and enhance the farming of lower trophic levels (herbivores and omnivorous species)

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[3] The term "trash fish" is unfortunate because many species involved are in fact species that would be suitable for human consumption if allowed to grow.

Use of common resources (land, water)

There can be spatial interactions between aquaculture and a wild-harvest fishery; both sectors can overlap and compete for port access and use of spatial areas (Hoagland and Powell, 2003). Conflicts are particularly common when aquaculture is introduced into a region where an open-access fishery is established. For example, new cage-culture farms can be placed in areas that were formerly used by fishermen directly for fishing or as passage to fishing areas. In many instances, fishermen and fish farmers may gain access to the aquatic system under different sets of rules and legal rights. Where such disparate property systems are not fully integrated and uses are partially or fully exclusive, conflicts are bound to arise. If property rights are ill-defined or if they are spread across a large number of users, then solutions may be difficult to realize.

The siting of an aquaculture facility, such as a net pen, longline or seafloor grow out, may displace some forms of fishing activity. This occurs when the wild stock is unavailable for harvest because of the failure of fish to migrate in or out of an area allocated to farms or because fishermen no longer have access to their fishing area. As more space is allocated for aquaculture, there may be both a smaller stock available for fishing and more congestion in the areas remaining open for wild harvest. These effects could lead to an increase in the cost of fishing. On the other hand, as more area is allocated for wild harvest, the cost of aquaculture might increase if the potential for achieving economies of scale is constrained. In some cases, the access of local fishermen to their resource is also restricted by aquaculture facilities due to the potential for robbery and vandalism. Some examples are provided in Box 2.

BOX 2. Examples of conflicts and synergies between fisheries and aquaculture using common coastal areas

In Chile, there are often conflicts between salmon farms and artisanal fishers for the use of coastal marine areas or access to these (Soto, Jara and Moreno, 2001). Often, salmon farms do not allow the latter to approach farms due to fear of robbery or vandalism to cages, while the fishermen complain that the farms are not allowing them to reach their traditional fishing grounds. A similar case can be described for shrimp farming areas in the Gulf of Fonseca, Nicaragua, where armed guards often keep fishermen away from large farms, not allowing access to their former and potential fishing channels and lagoons within the mangrove.

On the other hand, in some communities of the Asia-Pacific region, coastal artisanal fishers' livelihoods and sustenance depend on the coastal cage-culture farmers, who provide, almost on a daily basis, the only source of income, by providing trash fish to feed cultured stocks of high-value marine species such as groupers. The artisanal fishers may operate a variety of gear types, including large, stationary, semi-mechanically operated lift nets; gillnets; cast nets and weirs, and they can coexist well with aquaculture. This complementarity and livelihood interdependence has been ongoing for decades, without any one group being disadvantaged, and most of all, without apparent harmful impacts on the stocks.

Aquaculture modification of physical habitat

Some aquaculture structures have been likened to fish aggregation devices (FADs) (Dempster *et al.*, 2004), in that they provide substantial submerged structures that attract numerous fish species (Dempster *et al.*, 2002, 2005, 2010). However, unlike traditional FADs, sea-cage fish farms and shellfish longlines, racks and trays may also affect (both positively and negatively) the availability of food (i.e. through wastes and uneaten feed, and by providing substrate where organisms can grow and can be eaten) to wild fauna in their surrounding areas and therefore affect fisheries (Fernandez-Jover *et al.*, 2011).

Aquaculture practices have had extensive influence on some habitats. For example, pioneering shrimp farms negatively impacted mangrove forests in tropical countries. Building of ponds and modification of waterflows and hydrological regimes of tropical estuaries for aquaculture systems can have an impact on the life cycle and productivity of local fisheries depending on those habitats. Fish farms are common artificial elements in coastal ecosystems in cold temperate to tropical regions; cages are used for growing fish, while seaweeds, mussels, oysters and clams are grown on suspended ropes, racks or trays. These structures can occupy substantial coastal space. However, it is difficult to separate the effects caused by the structure from those derived from increased nutrient availability and food in general.

Aquaculture structures may therefore affect the presence, abundance, residence times and diets of fish in a given area and can, therefore, have important effects on fisheries. Aggregations of wild fish form around sea-cage fish farms, regardless of the cultured species they contain (e.g. salmonids, seabream, European seabass), wherever they occur in Europe (e.g. the Mediterranean Sea; (Dempster *et al.*, 2002, Fernandez-Jover *et al.*, 2011), the Canary Islands (Tuya *et al.*, 2006); and Norway (Dempster *et al.*, 2005)). Such aggregations of fish species that are typically targets of fisheries (e.g. carangids, mugilids and sparids in the Mediterranean, and gadoids in Scotland and Norway) in a concentrated area may affect local fisheries in several ways, including redistribution of stocks and aggregation of stocks, thereby increasing catch per unit effort (Box 3). In addition to sea-cage farms, fish aggregations have also been described around bivalve aquaculture rafts and longline installations (Laffargue, Bégout and Lagardère, 2006).

Cage farms in inland waters also serve as aggregating devices. This is particularly true for tilapia and pacu (*Piaractus mesopotamicus*) cultured in cages in Brazil, Colombia and Mexico, as well as rainbow trout (*Oncorhynchus mykiss*) cultured in Scottish lochs and salmon and trout cultured in Chilean lakes. In all cases, both wild fish and escapees congregate around the cages to feed on uneaten feed and organic wastes. Soto and Jara (2007) showed that native fish biomass and productivity can increase by up to four times near cages in oligotrophic lakes, and that the abundance of wild trout can increase by up to

10 times (see Box 3). Such increases in biomass and productivity are very often used by local recreational fisheries.

BOX 3. Examples of fish cages attracting and increasing wild fish and fishery productivity

In general fish-farming cages increase local fish abundance and often productivity through direct consumption of wasted pellet feeds and through increased local productivity. In Lake Llanquihue, southern Chile, bays with salmon farming have higher recreational fishing yield for trout and salmon, and fishermen often go near to the cages to fish. Occasionally the abundance of wild salmon and trout promotes fishing with gillnets by local fishermen, even though such practice is forbidden by law, as only recreational fisheries are possible in these lakes.

The table below shows the average values for freshwater fish biomass and productivity in Lake Llanquihue bays with salmon farms (N=4) and in control sites (bays without salmon farms; N=3). Biomass and productivity were evaluated by gill netting and echo-sounding (adapted from Soto and Jara 2007).

Wild fish	Bays	Biomass (kg/ha)	Productivity (kg/ha/year)
Salmon and trout*	With salmon farms	32.8	16.6
	Control sites	1.9	0.8
Native species**	With salmon farms	11.1	5.1
	Control sites	3.2	1.4

* Rainbow trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*) and Atlantic salmon (*Salmo salar*).

** Silversides (*Odontesthes mauleanum* and *Basilichthys australis*) creole perch (*Percichthys trucha*) and large whitebait (*Galaxias platei*).

Arechavala-Lopez *et al.* (2010) demonstrated that coastal aquaculture and local fisheries can be directly connected. They showed that wild bogue (*Boops boops*) that typically aggregate at fish farms form a significant component of the catch of local fisheries. Using the body fatty acid composition as a biomarker of pellet feeding, they traced fish that were resident around farms and consumed sufficient amounts of farm waste feed to modify their condition and fatty acid profiles as compared to those captured by a fishery that operated several kilometers distant from farms. Also, the farms significantly concentrated higher bogue biomass. In this case, fisheries at a local scale appear to benefit from a biomass export from fish farms.

Aquaculture structures also influence settlement processes for certain wild fish populations, although the overall importance of this to recruitment to populations is unknown. Information on the role of fish farms as settlement habitat is scarce. For Mediterranean fish farms, Fernandez-Jover *et al.,* (2007a,b) found that 20 juvenile fish species settle at farms throughout the year. The influence of fish cages on the pelagic postlarval stage could affect the connectivity between recruits and fishing stocks, through a spatial modification of the available settlement habitat, alteration of mortality and modification of trophic resources (e.g. increase of particulate organic matter or zooplankton abundance). Bivalve aquaculture structures also affect fish settlement. Algal and epibiontic growth on the bottom mesh used in bivalve aquaculture (as practiced in North Carolina and elsewhere) can enhance the nursery habitat for the many species that preferentially associate with seagrass habitat, at least as juveniles (Powers *et al*., 2007).

The effects of farms on fisheries described above usually take place at the waterbody scale as an aggregated result from several or clusters of fish farms. Up to 170 species of wild fish have been documented to associate with fish farms as adults or juveniles worldwide (Sanchez-Jerez *et al.,* 2008). Yet the overall effect on the associated fisheries yield (both food fisheries and recreational fisheries) has not been properly assessed at a wide scale.

The positive and negative issues related to habitat modifications and possible management solutions addressing the negative impacts within an EAA are given in Table 4.

TABLE 4
Issues related to habitat modifications and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative impacts
- Excessive finfish cage culture could result in the destruction of benthic habitat where fishery resources can otherwise develop or be dependent on (-) - Aquaculture can reduce access to the traditional fishing areas by local fishermen (-) - Transformation of natural coastal fishery habitats into fish ponds (-) - Fed aquaculture can provide additional nutrients, therefore in some cases supporting additional fisheries (+) - Fish cages can act as fish-aggregating devices, providing shelter to wild fish and potentially enhancing fisheries (+)	- Improve site selection for cages, avoiding sensitive habitats (wetlands, mangroves, etc.) and areas currently used by fisheries or as pathways to fisheries - Set production limits considering environmental carrying capacity - Develop integrated coastal zone management plans allocating aquaculture and fisheries access to optimize wild harvest and aquaculture production - Encourage “enhanced fisheries” and improved aquaculture-fisheries coupling by appropriate aquaculture site selection and planning, including stakeholder participation (specifically fisheries)

Issues related to aquaculture outputs

The following aquaculture outputs and related effects on fisheries are considered in this section: food production (most biomass resulting from aquaculture); production of seed for CBF; escapees and species introductions; release of nutrients, diseases, medications and chemicals; income, market and trade and impacts on fisheries will be also addressed.

Food production

Aquaculture provision of food fish can complement and supplement that provided by fisheries. Aquaculture can increase availability of good-quality food and has increased the awareness and consumption of fish products worldwide. In some cases, aquaculture can ease the pressure on wild fish stocks when fisheries delivery fails or is of less quantity or poorer quality. As an example, in the Amazon basin and other watersheds like those of the Orinoco and the Essequibo rivers, fish derived from aquaculture are available when the river is high and the fishery catches are low. The downside is that the aquaculture prices are low when the river is full and the fishery delivery is plentiful (Wiefelds pers. Obs.). Aquaculture production also has had an important impact on food quality and food safety when producing for export. These changes have also improved the fishery products, especially in the processing plants and through the market chain.

Seeds for culture-based fisheries and stock enhancement

Culture-based fisheries (CBF) is the provision of aquaculture-produced larvae or juveniles to supplement and improve the recruitment of one or more aquatic species and therefore raising the total production or the production of selected elements of a fishery beyond a level which is possible through natural processes. Cultured-based stock enhancement particularly emphasizes the releasing of seed produced in aquaculture installations, in addition to other enhancement measures such as improvement of habitat. The latter is often done to protect an endangered aquatic animal species whose population can not be sustained due to failure in key biological links such as reproduction and early stage development due to environmental change or human factors. Sea ranching, considered as another form of CBF, is the release of cultured juveniles into unenclosed marine and estuarine environments for harvest at a larger size in "put, grow and take" operations (Leber *et al.*, 2004).

CBF and stock enhancement takes place either in artificial waterbodies (e.g. dam lakes) where there may be no impact on natural populations, or in natural ecosystems such as lakes, lagoons and coastal marine areas, where environmental concerns include potential effects on the native fauna and the ecosystem in general.

The increasing capacity for massive production of seed in hatcheries has led to the growing and strengthening of CBF and stock enhancement programmes worldwide. These are becoming the major contributions of aquaculture to enhance fisheries in many parts of the world.

The potential of CBF was recognized long ago as a cost-effective means of increasing the food fish supplies in rural areas (Fernando and Ellepola, 1969; Mendis, 1977). However, the practice gained momentum more recently due to the increasing demand for fish, improvements in seed stock production and availability, and also as a major strategy by governments to increase food fish production and livelihoods, particularly in rural impoverished communities (Amarasinghe and Nguyen, 2009). In many instances, it is also seen as an environmentally minimally perturbing practice and a good example of multiple, effective use of water resources (De Silva, 2003).

Relevant marine stock enhancement activities have been taking place in many countries since early 1900, involving finfish, crustaceans and shellfish; therefore, enhanced stock and ocean ranching are increasingly contributing to marine capture fish production (Leber *et al*. 2004; Bartley and Leber, 2004). Li *et al.* (2009) recently reported that 94 countries are implementing different types of aquaculture-based fisheries involving some 180 species of aquatic animals globally. For instance, China's stock enhancement releasing programme involved over 100 species of aquatic animals with a total of 19.7 billion fingerlings/fry/fertilized eggs released to the sea, inland lakes, reservoirs and rivers in 2008

(Shi, 2009). It was reported that the Korean Government allocated a budget of USD$33.7 million for ocean ranching projects during 2002–2011 in the Yellow Sea, which involves target species such as of olive flounder (*Paralichthys olivaceus*), black rockfish (*Sebastes schlegeli Hilgendorf)*, flat greenling (Hexagrammos spp), Chinese shrimp (Fenneropenaeus chinensis), blue crab (*Scylla serrata*) and Manila clam (*Ruditapes philippinarum*). In China, it is estimated that such resource enhancement activities contributed to a catch increase of 120 000 tonnes, valued at USD 225 million in 2008. The cost/benefit ratio of resource enhancement is around 1:5. In other words, it profited 1.5 million professional fishers by USD150 per capita in China. The large-scale jellyfish releasing programme carried out in China's Liaoning Province significantly increased the catch of jellyfish, with the catch volume reaching 23 500 tonnes in 2009, which would profit the 130 000 fishers by nearly USD150 per capita (Liu, 2009).

Japan, which has a long history of marine ranching (FAO, 1999), also pioneered the use of the open seas for CBF. In this country, catch of released flounder reached 30–90 tonnes and comprised 4.6–20.1 percent of the landed weight and 3.5–14.8 percent of the landed value from 1996 to 2005. Recapture rates of released fish were 7.2–17.0 percent for 1996–2002 year-classes (Tomiyama, Watanabe and Fujita2008).

Other countries active in inland and marine stock enhancement include Australia, China, Denmark, France, Iceland, Iran, Korea, Norway, Spain, Thailand, the United Kingdom and the United States of America; and many island nations of Oceania have active programmes for restocking their indigenous populations of molluscs, such as giant clams, pearl oysters and snails.

In tropical developing countries, where the production of more fish for food is the goal of most fisheries activity, high-yielding herbivores, detritivores and planktivores (like tilapia and carp) are commonly stocked in lakes and reservoirs, specially in Asia (De Silva, 2003).

Within Latin America, the largest CBF efforts have involved exotic species. In Mexico, CBF of tilapia in lakes and impoundments is the most extensive enhancement programme. In 2007, this kind of production accounted for 96 percent of the total tilapia production in the country (66 000 tonnes in 2007). The tilapia fry production to sustain the CBF is mostly produced by government hatcheries. In Cuba, there have been important CBF efforts with common carp (*Cyprinus carpio*)*,* North African catfish (*Clarias gariepinus*) and tilapia. Many artificial lakes have been seeded with seed produced in government hatcheries. In Brazil, enhancement programmes are a strategy to preserve endemic species that have been subject to overfishing and to other anthropogenic impacts. This is the case with the pacu, a migratory species of the Paraná River basin in Paraguay and Uruguay, s whose populations are being progressively reduced. This species is highly valued commercially and socially.

The Chilean Government has promoted and assisted the release of fingerlings of rainbow and brown trout (*Salmo trutta*) in natural lakes and river systems since the late 1800s as an effort to develop recreational fisheries for these exotic species (*Soto et al.,* 2007). The seeding of some waterbodies continues in an attempt to provide good recreational fisheries opportunities, as trout and salmon are the only species legally available for such fisheries. Currently, recreational fisheries based on exotic trout and salmon are important sources of income and employment, not only in southern Chile but also in Argentina.

Ecological impacts of the salmon and trout introduced for recreational fishery purposes (and also as escapees from aquaculture) have been well described in several countries (McDowell 2003; Soto *et al*., 2007; Pascual *et al.*, 2007). However, for most species used (both native and exotic) in CBF worldwide, long-term impacts of such practices on biodiversity and structure and function of ecosystems have not been thoroughly examined, and this remains an important shortcoming of CBF.

Limited assessment efforts are often focused on the biological results of the release, for example, recapture rate and impact on fisheries (e.g. contribution of released seed to catch), while little is known on the economic efficiency and ecological impacts (Leber *et al*., 2004) (Box 4). For example, tilapia has been

BOX 4. Impacts of badly planned CBF due to modifications to the ecosystem structure and function

The major risks include the following:

i) poor performance of enhanced species, such as slow growth and small size caused by increased intraspecific competition for food and habitat due to larger densities by the addition of hatchery-reared fishes;

ii) possible structural changes in the aquatic community and ecosystem due to shifting prey-predator relationships and competition between hatchery-reared fish and individuals of the same species and other species with similar ecological requirements;

iii) transmission of pathogenic organisms when health is not managed in the production of fish seed used for release; and

iv) environmental modifications to natural habitats and breeding areas for fishery resources due to activities of introduced species (e.g. building of nests by tilapia).

Competition (inter and intraspecific) may lead to a reduction in abundances of competing species and prey species or even local extinctions due to increase in the abundance of released fish (Molony *et al*., 2003). Stock enhancement of certain fish species may cause adverse impacts on ecosystem functioning. For example, the grass carp (*Ctenopharyngodon idella*) release programme in East Lake, Wuhan, China caused significant damage to aquatic weeds in the lake which were absorbing nutrients and contributed to the deterioration of the water quality in the lake. Uncontrolled release of zooplankton-feeding fish may contribute to algal over-bloom and eutrophication of the waterbody. If health management is not adequate, there is great risk of introduction of diseases and parasites to the wild population owing to the low resistance of the wild population and difficulty of disease control in natural waterbodies.

BOX 5. Case examples of CBF positive impacts in Mexico

In Mexico, there is a CBF programme for the pike silverside (*Chirostoma estor*) fishery in Lake Patzcuaro, based on recent technological breakthroughs in the research of its intensive larval rearing (Ross, Martinez Palacios and Morales, 2008). The fishery for this species in Lake Patzcuaro is a source of income generation for almost 2 000 families, but has been steadily declining over the last decade due to uncontrolled exploitation. Current efforts by federal and state governments seek to establish a comprehensive CBF programme in which the technological element (fry production) is only one element, complemented with stakeholders' involvement and participatory approaches.

Another case is that of a native cichlid, the Mexican mojarra (*Cichlasoma urophthalmum*) in lagoons in the southern Mexican State of Tabasco. The private company Puctesa produces the fingerlings that, through CBF programmes of the State of Tabasco, are stocked in waterbodies of diverse size to sustain traditional small-scale fisheries in rural communities. Beginning in 2002, annual productions of at least 2 million fry have been stocked, with peaks in 2005 and 2006 of 12.5 million fry. As of 2005, an estimated 4 000 families had benefited from this programme.

used extensively for CBF in Asia, Latin America (see Box 5) and Africa, yet the potential negative impacts have been scarcely assessed. Canonico *et al.* (2005) suggested that tilapia introductions in aquatic ecosystems can have relevant negative effects on local biodiversity, while De Silva *et al.* (2004) suggested that tilapia would tend to invade those habitats that have been degraded from various anthropogenic impacts, and made unsuitable for indigenous species.

The positive and negative issues related to CBF and possible management solutions addressing the negative impacts within an EAA are given in Table 5.

TABLE 5
Issues related to CFB and stock enhancement impacting fisheries and management solutions within an EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative impacts
- Stocking and CBF may affect wild populations through the transmission of diseases, increased competition, predation, modification of habitats and disruption of the structure and function of aquatic ecosystems (-) - Negative genetic impacts including interbreeding between hatchery-originated individuals and wild populations pose short-term hazards for the fitness and productivity of the wild fish which might be reduced by outbreeding depression, giving a loss of local adaptation and in the long term, genetic variability between natural populations might be reduced - Aquaculture-based stock enhancement programmes can significantly contribute to capture fisheries (+) - CBF brings about significant positive impacts on livelihoods and food fish supplies of rural communities in many countries world-wide (+) - Responsible aquaculture-based stock enhancement contributes to the conservation and improvement of certain fisheries through enhancement of endangered species (+)	- Promote risk assessment and monitoring of CBF and restocking programmes - Follow national regulations and international guidelines for the introduction and movement of non-native species/strains to the wild and for culture (FAO, 1995; ICES, 2005) - Select native broodstock for the production of eggs and juvenile releases (genetic profile of broodstocks) - Create a database for origin and genetic diversity of cultured stocks - Assess the genetic diversity of cultured stocks - Promote stock identification and differentiate stocked from wild fish

Aquaculture escapees and their impacts on fisheries

Escapes of juvenile or adult fish are a constant possibility if operational or technical failures occur at fish farms. A single fish farm may hold hundreds of thousands to millions of cultured fish. In the Mediterranean Sea, approximately 500 million seabass and 450 million seabream are held in sea cages, with wild stock numbers believed to be considerably lower (ICES, 2006). Similarly, over 300 million Atlantic salmon are held in sea-cages in Norway at any given time (Norwegian Fisheries Directorate, 2009), far outnumbering the approximately 1 million salmon that return to Norwegian rivers from the ocean each year to spawn. In 2008, in Chile, the total production of salmonid species was 500 000 tonnes (*Fishstat plus*, FAO, 2010c); that means there were about 180 million salmon (mostly Atlantic salmon) in sea cages in the southern fjords, where salmonids are not native.

In some cases, due to the large numerical imbalances of caged compared to wild populations, escape raises important concerns of ecological and genetic impacts. Such impacts are very similar to those described in the case of stock enhancement and CBF.

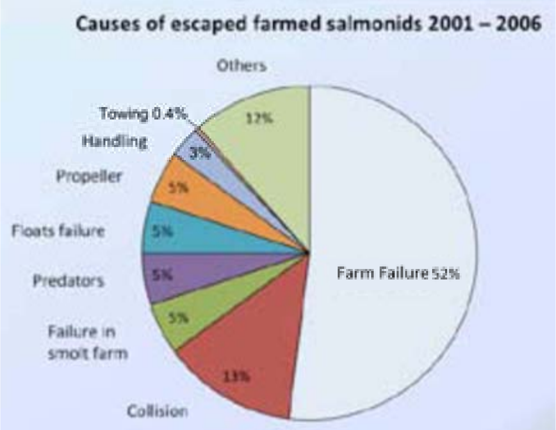
The evidence of ecological effects of escapees on wild populations is largely limited to salmonids, as these interactions have been well documented, with more limited and general information for other species such as tilapia (De Silva *et al.*, 2004; Canonico *et al.*, 2005). The potential ecological risks from escaped farmed fish to fisheries are similar to those described in the case of stocking, that is, they may affect wild populations through the transmission of diseases, increased competition and predation, and genetic interactions. Farmed fish can interbreed with wild fish stocks. In this way, the new generation of wild fish, whose traits have developed over thousands of years of evolution, will be genetically mixed with genes from a more uniform farmed stock. In the long run, this may change the wild stock to the extent that it no longer will be able to survive in its original environment. Some interspecific hybridization might also occur should farmed fish escape into an ecosystem where there are very closely related species. Escaped fish can compete for mates or nesting sites. In Norway, escaped farmed fish have been observed digging up and destroying established wild salmon spawning beds.

Farmed fish can escape directly from net-pens and other enclosures due to human error, damage from catastrophic natural events such as severe storms, or following damage to structures by predatory marine mammals. This is well illustrated for salmon (Box 6). Some species of finfish and shellfish that spawn freely in captivity and produce pelagic eggs may release fertilized gametes into the surrounding environment. All these possible risks are believed to pose a greater threat to natural populations (conspecifics of the escapees) than to other fish populations at large.

BOX 6. Escape of farmed salmon in Norway

The main proportion of escaped salmon in Norway is the result of strong weather forces. The Norwegian coastline is rough, and those who want to engage in farming activities must ensure that their facilities can withstand the occasional storm.

The categories "farm failure", "propeller damage", "handling" and "failure in smolt farm" comprise of 65 percent of the number of escaped fish in salmon farming. For these four categories, most of the responsibility lies with the farmer and or provider of equipment and services such as transport (wellboats), hatchery, etc. Escapes as a result of storms are included in the "farm failure" category. Storms cannot be blamed on the farmer, but the farmer is responsible for making sure that his/her farms can withstand normal weather conditions, including storms.



The unintentional or accidental release of cultured organisms from culture farms into the wild is enhanced by factors such as the continuity of aquatic ecosystems, the number of operating farms and the high mobility of many farmed aquatic species.

The number of farmed salmon escaping to the wild is large relative to the abundance of their wild conspecifics (Thorstad *et al.*, 2008). The most relevant effect seems to be outbreeding depression of wild conspecifics. Escaped farmed salmon are clearly an international issue, with frequent observation of their crossing national borders.

Escapees can eventually establish self-sustained populations as introduced species or alien species (Box 7). Impacts of introduced species fall into two broad categories: ecological impacts, which include biological and genetic effects, and socio-economic impacts. However, these two categories are not independent, and socio-economic changes to fisheries brought about by alien species can in turn cause more ecological changes. Thus, a reduction in native species may be from direct interaction with an exotic species, or it may result from increased fishing pressure or changes in land use brought about by the presence of a newly established species.

However aquaculture production based on alien species could have indirect positive effects on fisheries; for example, the introduction of the whiteleg shrimp (*Litopenaeus vannamei*) into Asia for aquaculture development has significantly reduced the pressure on native giant tiger shrimp (*Penaeus monodon*) larvae and wild broodstock, and therefore it is possible that more shrimp stock could be available to higher-value fisheries.

BOX 7. Reproductive success of escapees

Escaped salmon do not appear to greatly benefit local fisheries in Europe, other than through short-term captures after escape incidents; however, escapees may support local fisheries to an extent in certain conditions. Deliberately released gilthead seabream (*Sparus aurata*) in the Mediterranean Sea were able to adjust to a natural diet and subsequently grew well, indicating they adapted to life in the wild and likely added to local population numbers (Sánchez-Lamadrid, 2004). In addition, while small-scale escape events are relatively frequent, very few escaped seabream or seabass occur near the sea-cages from which they escaped (Dempster *et al.*, 2002), which suggests that escapees move away from farms to other more favourable habitats, or that they are fished by sport and professional fisheries. Similarly, recaptures of Atlantic cod (*Gadus morhua*) escapees in local commercial and recreational fisheries in Norway are high (approximately 40 percent; Uglem *et al*., 2008), indicating that local fisheries receive temporary increases after escape events.

Escapes of chinook salmon (*Oncorhynchus tshawytscha*) in southern Chile have generated a successful population of this species running up rivers both in Chile and Argentina and being actively used for recreational fisheries (Soto *et al.*, 2007). However major escapes of Atlantic salmon in this country do not seem to have generated successful reproductive populations (Thorstad *et al*., 2008).

The positive and negative issues related to aquaculture escapees and introductions and possible management solutions addressing the negative impacts within an EAA are given in Table 6.

TABLE 6
Issues related to aquaculture escapees and introductions and possible management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
- Escape fish may affect wild populations through the transmission of diseases, increased competition, predation, modification of habitats and disrupton of the structure and function of aquatic ecosystems (-) - When escaped fish have conspecifics in the area, interbreeding between hatchery-originated individuals and wild populations poses a short-term hazard for the fitness and productivity of the wild fish, which might be reduced by outbreeding depression, giving a loss of local adaptation and in the long term, genetic variability between natural populations might be reduced - In some instances, escapes can increase catches in local fisheries (e.g. salmon artisanal and recreational fisheries in Chile) (+)	- Ensure containment measures for cage farming (e.g. quality, design and strength of nets for cages; encourage the use of anti-predator nets) - Ensure aquaculture breeding programmes do not lead to inbreeding - Encourage containment measures for land-based water effluents (e.g. use of nets, trap cages) - Site aquaculture away from wild fish migratory routes - Devise mitigation measures such as capturing the escapees, encouraging a short-term fishery if appropriate and legally feasible

Interactions and impacts resulting from release of organic and inorganic nutrients

Whether a nutrient becomes a pollutant in an aquatic system is a function of whether it is a limiting nutrient in a given environment, its concentration, and the carrying capacity of that ecosystem. In fresh waters, phosphorus is typically the limiting nutrient (Hudson, Taylor and Schindler, 2000), so its addition will dictate the amount of primary production (algal growth). In marine environments, nitrogen is typically the limiting nutrient (Howarth and Marino, 2003), so its addition will do likewise.

Soluble nutrients coming from the digestion processes of farmed aquatic animals will dissolve in the water column, and their initial dilution and transport is a function of water current dynamics. Solid waste made up of uneaten feed pellets, feed fines (fine particulates caused by pellet damage during transport or automatic feeding systems) and faecal material can also accumulate below culture cages and in the outflows of aquaculture facilities. The accumulation will also depend on the local currents and depth.

Since nitrogen and phosphorus are released from fish cages and fish or shrimp ponds, there is always the potential for fish culture to promote eutrophic conditions, either by supplying a readily available nutrient source directly to phytoplankton or by oxygen removal, accompanied by nutrient release and via the decomposition of waste solids. High nutrient concentrations can also trigger algal blooms which reduce water clarity (and consequently sunlight availability in the water column to other organisms), and can strip oxygen from the water column when the organisms die, sink and decompose (Gowen, 1994).

Eutrophication, low oxygen events and fish kills affecting local fisheries are common events in some lakes and reservoirs in Asia where there is a high density of small-scale fish-cage farms that together produce excess nutrients in dissolved and particulate form and therefore exceed the carrying capacity of the waterbody (e.g. in Indonesia; Abery *et al.*, 2005).

Organic enrichment of the seabed is the most widely known effect of fish farming globally. Such effects have been reported from various parts of the world, including Scotland (Gowen, Bradbury and Brown,1985), the east coast of Canada (Hargrave *et al.*, 1993), the Northeastern Pacific (Weston, 1990), Chile (Soto and Norambuena, 2004) and the Mediterranean (Karakassis *et al.*, 2000; Karakassis, Pitta and Krom, 2005). This can impact benthic (e.g. seagrasses) and other sensitive habitats (e.g. corals) close to the farm (Holmer *et al.*, 2008). These areas are often very important as food sources or habitats for local wild fisheries.

However, in many cases, additional nutrients can also provide more food and enhance local fisheries (Boxes 8 and 9). This potential positive effect, i.e. stimulation of growth of some fish species, needs to be weighted against possible impacts on ecosystem structures and functions that may lead to changes in species populations being targeted by the fishing industry.

The positive and negative issues related to organic and inorganic output by aquaculture and possible management solutions addressing the negative impacts within an EAA are given in Table 7.

BOX 8. Aggregation of wild fish beneath fish cages due to feed availability

The interaction of farmed and wild fish in the Mediterranean has been addressed by various authors during the past years. McDougall and Black (1999) reporting data from the Mediterranean and Angel, Krost and Gordin, (1995) from the Gulf of Aqaba have attributed the relatively low impacts of organic enrichment on the seabed to the consumption of the organic matter by demersal fish and invertebrates. Underwater diving and video surveys beneath fish farms in the western and eastern Mediterranean (Dempster *et al.*, 2002; Vega Fernandez *et al.*, 2003; Golani 2003) confirmed that large numbers of fish of various species were aggregated under the fish cages during feed supply. This aggregation of wild fish has been shown to be related to the feed supply rather than to a fish aggregating device (FAD) effect (Tuya *et al.*, 2006), and their densities approach "normal" densities after the cessation of fish farming. Dempster *et al.* (2002) have shown that the abundance, biomass and species richness of the aggregating fish assemblages are negatively correlated to distance from shore and positively correlated with the size of the farm. These authors suggest that coastal cage fish farms may act as small pelagic marine protected areas (MPAs), although in a later paper (Dempster *et al.*, 2004), they also emphasized the potential effects of such large aggregations, including increased vulnerability to fishing and pathogen transfer between caged and wild fish. Vita *et al.* (2004) conducted field experiments with sediment traps and concluded that 80 percent of the particulate organic matter leaving the rearing net-pens may be consumed before settling on the seabed, and they have attributed a large part of this consumption to the wild fish aggregating beneath the farms. On the other hand, Dempster *et al*. (2005) have shown that there are differences between aggregations in the Mediterranean and other sites regarding the vertical variability of the wild fish assemblages, thereby concluding that there is some uncertainty in modelling nutrient dispersal prior to the installation of fish cages.

BOX 9. Increasing fishery productivity

Aquaculture can especially increase fishery productivity through additional nutrient and feed outputs (e.g. from cages) in oligotrophic ecosystems, and provision of refuge (e.g. fish cages, mussel rafts) in most environments. In the oligotrophic Mediterranean Sea, cage aquaculture is responsible for less than 5 percent of the anthropogenic input of nutrients (Karakassis, Pitta and Krom, 2005). However, farms are typically clustered in specific regions, thus their influence in regional nutrient budgets may be significantly higher. Machias *et al.* (2005, 2006) suggest that nutrients originating from sea-cage aquaculture in Greece have resulted in increased primary productivity in specific regions and led to increases in wild fish populations and a doubling of fisheries landings in regions with fish farms as opposed to regions without fish farms. In Spain, increased commercial and recreational fishing around fish farms has been reported. Farm-associated fish have been identified in samples from local fish markets through their distinct farm-modified fatty acid profiles (Fernandez-Jover *et al.*, 2007a; Arechavala *et al.*, 2010). In Norway, local fishermen report relatively high amounts of saithe (*Pollachius virens*) with salmon pellets in their stomach. In general, farm-associated saithe are significantly fatter and have much larger livers that non-associated fish (Dempster *et al.*, 2011). Previous studies have also shown that saithe caught, tagged and released at a salmon farm later occurred in the catches of commercial fishermen (Bjordal and Skar, 1992). In this regard, most of the aggregated species can be considered as "type B" (species attracted to artificial reefs but also taking some production benefit from the

BOX 9. (Continued)

reef), following the model proposed by Bortone (2007), because of the use of feeding resources provided by the artificial habitat and lost food pellets. Therefore, marine farms can provide one of the functions of marine protected areas (Forcada *et al.*, 2009), by increasing the export of fish biomass. If restrictions on fishing are applied within farm leasehold areas, it has been suggested that coastal sea-cage fish farms may act as small (up to 160 000 m^2) pelagic marine protected areas (Dempster *et al.*, 2002, 2006; Soto and Jara, 2007).

TABLE 7
Issues related to organic and inorganic nutrient output by aquaculture impacting fisheries and management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
- Excess nutrient output can increase dissolved nutrient concentrations, leading to eutrophication and fisheries declines (-) - Excess nutrient output can lead to build up of particulate organic matter on the sea/lake bed, affecting benthic diversity and productivity and fisheries that depend on these resources (-) - Particulate matter coming from fish cages can smother seagrasses and corals, affecting fisheries that depend on them (-) - Dissolved nutrients increasing primary productivity could have a positive effect on wild fish biomass (+)	- Improve feed conversion factor - Promote research for improvement of feed quality (e.g. use feed ingredients with high digestibility) - Undertake carrying capacity estimations so that the environment can assimilate the nutrients released - Encourage environmental impact assessment and monitoring systems and integrated environmental assessments at the watershed scale, if appropriate - Improve site selection identification and suitability, avoiding sensitive habitats - Improve research and monitoring of waste management - Improve nutrient re-utilization by wider implementation of integrated aquaculture

Interactions and impacts resulting from release of diseases and parasites

Both cultured and wild fish are susceptible to the same pathogens and the same parasites in the aquatic environment, but it is likely that intensive aquaculture conditions increase their prevalence within the farm. Therefore, the risk of transmission of pathogens and parasites between wild and cultured fish is possibly increased as water moves freely between farm enclosures and the open environment, or when farmed fish escape and intermingle with wild fish. Aquaculture has been blamed for transmitting parasites and endangering wild fisheries. Costello (2009) presents evidence that salmon farms are the most significant source of sea lice on juvenile wild salmonids in Europe and North America. Krkošek *et al.* (2007) describe the impact of sealice infestation on pink salmon (*Oncorhynchus gorbuscha*) in Pacific Canada, sealice apparently causing significant declines in the wild populations of the species, although the latter impact has been challenged, since wild populations have recently had major increases. The decimation of the oyster industry (both fisheries and aquaculture) in Europe was due to disease apparently resulting from the transboundary movement of seed from places where the disease was present, to new culture areas.[4] The pilchards imported for feed to Australian tuna farms

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[4] See: www.fao.org/fishery/culturedspecies/Ostrea_edulis/en

TABLE 8
Issues related to transfer of parasites and diseases between cultured and wild fish and management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for negative effects
- Transfer of pathogens from farmed to wild fish (-) - Transfer of pathogens from wild fish to farmed fish (-)	- Follow national regulations and international guidelines for the introduction and movement of live non-native species/strains to the wild and for culture* or as feed for aquaculture - Follow national and international norms and regulations for the management of aquatic animal health (e.g. OIE, 2011) - Implement biosecurity frameworks including adequate control of seed quality and transport pathways (disease) and quarantine for non-native seed, rapid and safe harvest of diseased fish, adequate collection and elimination of dead fish outside the waterbody - Prevent escapes* - Improve husbandry and keep farmed densities low enough to avoid stress - Conduct monitoring and surveillance of diseases in wild fish surrounding farm sites

* As in Table 6.

are believed to have caused the massive viral epidemics starting in 1995 that killed a large proportion of the wild adult pilchard population in South Australian waters (Thorpe *et al*., 1997).

Despite the above examples, much more is known regarding disease interactions among the host, the pathogen and the environment of cultured fish than for wild fish populations, because cultured fish are more easily observed. Also, once wild fish are infected by aquaculture farms or by other vectors, because of their low density, the disease is usually become less prevalence unless fish form large schools around cages. Clearly, scientific information on disease interchange between wild and farmed fish is still scarce and the evidence of impacts is variable (McVicar *et al.* 2006).

The issues related to transfer of parasites and diseases and possible management solutions within an EAA are given in Table 8.

Interactions and impacts resulting from release of drugs and chemicals

Like any land-based form of raising livestock where large numbers of animals are placed in a very limited space, aquaculture can provide various diseases and parasites with the ideal conditions to spread. Antibiotics and other chemicals can be administered to fish through medicated feed or through external treatments.

Antibiotics can be ingested by wild fish directly when they eat medicated feed that falls through the cages. These fish, in turn, may be caught and eaten by people, who thereby ingest limited amounts of antibiotic (Cabello 2006). This is undesirable, when one considers the development of bacterial resistance in people. The general perception is that residues of these medications, however administered, will be taken up by the benthic infauna and epifauna to their detriment, and will bioconcentrate up the food chain, reducing the resistance to disease of demersal and pelagic fish and thus affecting fisheries. However, there is almost no direct evidence of such effects. Although there are relevant reviews of chemical use in aquaculture, including products not related to disease treatment containing elements such as copper and zinc, the potential impacts of these on fisheries and ecosystems need to be studied in more depth (Burridge *et al.* 2010).

Management solutions within EAA are similar to those indicated in Table 8. The responsible use of veterinary medicines and other chemicals in aquaculture must be included as relevant measures.

Income and increased livelihood opportunities

In general, the major contributions of aquaculture towards the improvement of human well-being are found in the wider economy and the sector as a whole. Here, job creation and investment opportunities not only involve fish farming, but also those activities that are involved in servicing fish farming (e.g. supply and servicing of the main equipment, production and cleaning of nets and rafts, veterinary services, feed production), processing, marketing, sales and transport. Small-scale fishermen, struggling with making fishing a viable livelihood, now often want to become fish farmers, as they find new opportunities in this sector. Also, aquaculture production and processing offers many livelihood opportunities to women, who often come from coastal fishing communities. This has been the case with salmon farming in southern Chile, with shrimp farming in countries such as Brazil and Nicaragua (Wurmann, 2011), and with catfish culture in Viet Nam (De Silva and Phuong, 2011; Davy *et al.,* 2012). In many countries there is constant movement between fishing and aquaculture; for example in Scotland, a significant proportion of fishermen would be willing to be fish farmers, and vice versa.[5]

Fisheries and aquaculture provide direct and indirect livelihood support to millions of people. In 2008, out of an estimated 44.9 million people who were directly engaged full time or part time in capture fisheries or aquaculture, an estimated 10.7 million were involved in aquaculture, or about one-quarter (24 percent) of the total number of workers, the largest proportion (more than 90 percent) being in Asia (FAO, 2011. However, progress towards carrying out socio-economic evaluations of the effect of the aquaculture industry on local communities and its interaction with employment in coastal fisheries and other local opportunities has been slow. Relatively little is known about fishermen's behaviour, preferences and strategies when confronted with an expanding aquaculture industry, taking into account the availability of other employment

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[5] AQCESS (www.abdn.ac.uk/aqcess).

opportunities. The consequences of changing coastal fishery patterns and management regimes on aquaculture opportunities, given other employment opportunities or drift to unemployment should be assessed to evaluate prospects for expansion of either of these industries.

There are some examples of aquaculture reducing the fishing stress on depleted populations by providing alternative income and opportunities to fishermen. For example, the culture of groupers is increasingly satisfying market demand and so is reducing fishing pressure on wild grouper stocks and the consequent reduction of use of destructive fishing methods. Aquaculture's facilitation of fragile habitat preservation (e.g. coral reefs) could also ensure longer-term fishery of this and other species associated with the reefs (De Silva and Phillips, 2007).

As an indirect effect of increased production and income, the growth of aquaculture has enhanced the strengthening of many fisheries institutions worldwide. Such is the case of Brazil, where the growing opportunities of the sector have contributed to the reorganization of the fisheries and aquaculture institution through the creation of the Fisheries and Aquaculture Ministry. This has also occurred in Chile and in Viet Nam (World Bank, 2005), where the rapid development of aquaculture has resulted in the strengthening of government fisheries and aquaculture institutions.

Aquaculture and fisheries interactions through markets and postharvest processes

The volume of world aquaculture production is currently becoming closer to the volume of world fisheries production for human consumption (FAO, 2011. Aquaculture production will continue to expand and have dramatic impacts on markets for wild fisheries. For example, prices paid to wild salmon fishermen and processors in the United States of America fell dramatically as world farmed salmon production expanded during the 1990s, causing significant economic difficulties for Alaskan salmon fishermen, processors and fishing communities (Knapp, Roheim and Anderson, 2007). United States shrimp fishermen have experienced similar effects of competition from farmed shrimp. Aquaculture development has been partly stimulated by overfishing of wild stocks, which has resulted in the inability of the capture fisheries sector to meet the growing demand for wholesome seafood products. Salmon farming emerged in the 1980s as wild stocks of coho and chinook salmon in North America dwindled and Atlantic salmon stocks were threatened in both America and Europe due to overfishing and loss of habitat. Growth in catfish and tilapia aquaculture has satisfied market demand in the whitefish markets, as harvests of the wild product have decreased considerably. Falling supplies of wild ground fish have also stimulated commercial production of farm-raised cod in Norway. In each of these cases, the aquaculture sector has emerged to increase fish supplies and try to meet the market demand.

Nearly 65 percent of shrimp consumed is produced by aquaculture, a result of continuing consumption linked to increasing incomes. On the other hand, aquaculture has been successful in bringing affordable fish (and protein) to consumers. It has also expanded availability of product to consumers, both in terms of geographic coverage and by prolonging (even abolishing) seasonality, and therefore, it has encouraged fish market development.

Aquaculture has also helped the fishery sector develop much more sophisticated distribution and logistics networks. For example, farmed salmon has greatly expanded and created new market opportunities for wild salmon. Farmed salmon has benefited consumers by lowering prices, expanding supply, developing new products and improving the quality of both farmed and wild salmon (Knapp, 2007).

Markets for aquaculture species and for wild fisheries products are considered "markets for seafood" (including freshwater species). However, for some species there is differentiation between the farmed and wild product, as in salmon and in some cases, for seabream and seabass, appealing to different customers and achieving different market price. Some consumers perceive wild fish as superior to farmed fish and are willing to pay a higher "premium" price for wild fish (e.g. the higher price of wild-caught as compared to farmed seabass in the Mediterranean markets). This is also true in many Asian countries; when wild-caught counterparts are preferred, most market prices for the former are about 20–30 percent higher than that of the cultured commodities (Knapp pers. obs). In some cases, such preference works against aquaculture market prices and final benefits for the producers. However, most consumers worldwide, care more for price, and therefore larger aquaculture outputs of a species that has a wild counterpart will lower the price of both types of fish. This could be also the case if there is a larger output of wild fish of similar quality. In general, the degree of market interaction between fisheries and aquaculture depends on the total output (fisheries plus aquaculture) and the market's ability to distinguish between the two origins. The latter is influenced by the industry's ability to highlight those differences in their marketing strategies.

The positive and negative issues related to markets and possible management solutions addressing the negative impacts within an EAA are given in Table 9.

Issues related to governance and ability to achieve

For most issues dealing with aquaculture inputs, resource use and outputs, there are key common governance root-problems/governance issues. The most common issues include the existence of non-related policies for fisheries and aquaculture, lack of integrated planning, of communication, of understanding of the interactions, of adequate research, of training and insufficient consideration of the different nested geographical scales (Figure 6). In general, there is a lack of an ecosystem approach to fish production in general.

TABLE 9
Issues related to conflicts and synergies between aquaculture and fisheries in the market and management solutions within EAA

Impacts and sign of effects (- or +)	Possible management solutions for the negative effects
- Aquaculture can supply a homogeneous product of similar size, quality and consistency throughout the year compared to fisheries (- for fisheries) - Aquaculture has been forced to understand and respond to the needs of consumers and customers with the development of a range of product forms, quality standards, packaging, and timing and volume of fish deliveries, long-term contracts, supply guarantees, payment terms, etc. This has facilitated the way towards better postharvest standards for fisheries (+ for fisheries and for the consumer) - Aquaculture has often lowered fish prices through increased and continuous supply, market access and market competition (-for fisheries) - Aquaculture production is changing consumer behaviour, resulting in the development of new markets and increased fish consumption (+ for fisheries)	- Improve fishing techniques and processing of fishery products - Find alternative fishing resources - Move from fisheries to aquaculture - Develop intersectoral marketing strategies with strong focus on quality of products - Differentiate aquaculture and fisheries pricing structures - Focus fisheries more on marketing, segmentation and more forward integration into the value-chain - Develop policies that would provide incentive to value and not just to volume - Involve the fishermen more in management

Other external factors affecting ability to achieve (such as climate change) can exacerbate some negative interactions. For example, increased temperatures can enhance aquaculture-induced eutrophication processes, with negative impacts on fisheries (Table 7). Also, climate change can affect fishmeal fisheries and reduce availability of related ingredients for aquaculture feeds, although a positive downside to this is that aquaculture can be forced to reduce its dependency on these fisheries (De Silva, 2012).

Prioritization of issues: assessing the risks

As seen in the previous section, aquaculture-fisheries interactions and issues differ among countries and regions. For example, in some places escapees are seen as threats to fisheries, while in others, aquaculture-based stocking of waterbodies is seen as a solution for food security, and perhaps risks are underestimated.

In following the steps recommended in Figure 2, after the scoping and issue identification (done for a particular location, waterbody, country, etc.), it is necessary to focus on those issues and threats that could become major obstacles to achieve the high-level policy goals and management objectives for the fish production sector (fisheries and aquaculture).

The outcomes from this activity should be a decision for each of the identified issues as to whether or not there should be direct intervention, and if so, how soon and resources required (FAO, 2010b, FAO EAF toolbox)[6]. Most robust

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[6] www.fao.org/fishery/eaf-net/topic/166272/en

prioritization processes are based on risk assessment[7] using formal risk assessment methods (Arthur *et al.*, 2009). In some instances, it is possible to address prioritization of issues through participatory stakeholder analysis in the form of simple risk ranking with minimal levels of data and high stakeholder involvement. Within the context of the present analysis, we are dealing with a hazard generated by an organism (e.g. escaped fish), a physical condition (e.g. release of antibiotics or other chemicals), an action (e.g. the clearing of a mangrove area to build aquaculture ponds), etc. that may cause harm and therefore potentially create a risk for fisheries. Furthermore, risk assessment should be done for all the environmental, social and governance issues in order to identify those that require direct intervention and the level of urgency.

Developing the management system to minimize aquaculture`s negative effects on fisheries

In the previous section, we have identified the main issues and provided a summary of potential management measures. In this section, we summarize the next steps using some elements of the tool box template developed for the ecosystem approach to fisheries (FAO EAF Toolbox) and the EAA guidelines (FAO 2010b).

Setting operational objectives

After identifying the issues (ecological, social, economic or institutional) that require direct intervention, the next step is to develop a management system that will deliver successful outcomes. This requires clearly specifying what we want to achieve and what level of better outcome we are aiming at with the proposed management measures. These are known as operational objectives, and they need to be clear, measurable, time bound and directly linked to one or more of the high-level objectives and policies (Figure 2). For example, to address issues identified in Table 7, an operational objective could be to reduce farm nutrient outputs that induce eutrophication and fishery losses in a lake (fish kills by oxygen depletion) by 30 percent annually. As another example, an operational objective to deal with issues in Table 6 could be to reduce fish escapes from farms by 50 percent in the next two years and by 80 percent in the next four years.

Operational objectives should be developed in consultation with stakeholders because they define precisely what the management plan is designed to achieve and therefore what changes and improvements are required in aquaculture systems and their management, in the related fisheries and any other arrangements that may need to change.

To assess effectiveness of the measures in achieving operational objectives, there needs to be a way of evaluating the success of the management system. This requires indicators to measure performance and also targets (limit value,

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[7] Risk assessment is the process of assessing the likelihood and consequences of an event.

threshold, etc.). For example, for the first case above, we could use the feed conversion ratio (FCR) and aquaculture biomass per area as indicators. Indicators and targets would have to be agreed upon by the relevant stakeholders based on the best available information.

The monitoring of indicators, survey type and frequency should be proportional to both the predicted and actual impacts. Monitoring programmes and the use of indicators can be conducted at different levels. Farmers and/or authorities can perform simple and inexpensive surveys when impacts are expected to be minor. The outputs of the surveys should be an impact mitigation plan to take corrective actions over the management measures. It could also involve a review of the targets to make them more realistic.

Management measures/options

A critical step of the management system is to determine which management measure or combination of measures will most likely achieve each of the operational objectives given the available resources and any other constraints. This involves assessing which of the current formal or informal arrangements have deficiencies or inefficiencies and identifying potentially better alternatives. Each option should be evaluated based on its cost effectiveness, impact on risks and operational objectives, likelihood of adoption, etc. to determine which is the most appropriate. Many of the management measures must involve not only EAA but also EAF, especially when dealing with issues such as fisheries for wild seed or the management of fisheries to produce fishmeal or fish oil for pelleted feeds or for direct feeding with wet fish.

Tables 2 to 9 above identified the main issues and proposed management measures, some of which are expanded upon in the sections below.

Risk analysis and environmental impact assessment

A number of frameworks have been developed to minimize aquaculture`s environmental and social risks, including the *Code of Conduct for Responsible Fisheries* (FAO 1995) and various guidelines for aquaculture development in support of the code (e.g. FAO 1996, 1997, 2010b).

Management measures should include some form of environmental impact assessment (EIA) and/or risk analysis (see Arthur *et al*., 2009; FAO, 2009) prior to embarking on aquaculture activities that may impact aquatic environments and fisheries, including as well the monitoring of ecosystem and fishery changes; for example, this should always be done when using alien species or strains.

In the case of alien species, the solution is not to ban these – or to abandon regulation of their movement – but rather to assess associated risks and benefits to local fisheries, and then, if appropriate, develop and implement a plan for their responsible use. Relevant measures and recommendations for the use and movement of alien species and strains for aquaculture and CBF can be found in several institutional frameworks and documents. Good examples are the advice produced by the European Inland Fishery Advisory Commission (EIFAC*)* (Turner, 1988), the *Code of Practice on the Introductions and Transfers of Marine Organisms* produced by the International Council for the Exploration of the Sea (ICES, 1995), the FAO guidelines on *Health Management for Responsible Movement of Live Aquatic Animals* (FAO, 2007), and the guidelines on genetic resource management (FAO, 2008), among others.

Proper siting and consideration of carrying capacity

Aquaculture production facilities should adjust their production to the carrying capacity of the relevant waterbody and socio-economic system; this including fisheries. Each ecosystem has a different capacity to absorb and assimilate excess loading of organic compounds and nutrients from a farm or capacity to absorb social changes, habitat modifications, etc. that come with the farm. There is a need to examine carefully the desirability of different nutrient levels in different parts of an aqua-fish-ecosystem from the perspectives of the various users, and in terms of the stability of the system as a whole.

Many of the space and habitat-related impacts of aquaculture development on traditional fisheries can be reduced or eliminated through adequate siting and zoning of aquaculture areas. Zoning or allocation of space is a mechanism for more integrated planning of aquaculture development to avoid conflicts with fisheries (e.g. sensitive wild fisheries, spawning and nursery areas), as well as its better regulation. There is much literature and guidance relating to integrated natural resource management such as integrated coastal zone management (ICZM) and integrated watershed management (IWSM).

There are geographic information system (GIS) tools that can assist decision-making for site selection and modelling within and among all boundaries associated with aquaculture development and management, including the spatial requirements and boundaries for relevant fisheries. Modeling the nutrient budgets for individual farms could help find the optimal balance of nutrient release to minimize impacts on fisheries or even to enhance primary productivity in support of wild fisheries. There are many immediately available decision-making tools that could be used and many aquaculture models (e.g. carrying capacity) can be run inside GIS, or be spatially related to optimize aquaculture-fisheries interactions by GIS (Aguilar-Manjarrez, Kapetsky and Soto, 2010)[8].

Better management practices (BMPs) and codes of practice (COPs)

BMPs are a practical and economically feasible way to reduce adverse environmental impacts of aquaculture at the farm level and also at larger

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[8] Also see GISFISH (www.fao.org/fishery/gisfish/index.jsp).

scale, and so reduce conflicts with fisheries (Mohan and De Silva, 2010). Implementing BMPs requires action from both government (in the form of better policy, regulation, enforcement and planning and management procedures) and industry (through BMPs). However, BMPs must consider the monitoring and adaptive management of the added impacts of many farms, and therefore the need to consider the aquaculture zone and/or watershed scale. BMPs and COPs can involve, for example, more efficient ways to reduce feed losses and to improve FCRs, therefore reducing the nutrient release to waterbodies. They can also involve practices that minimize the risks of escapees from farms, the spread of diseases, etc.

Discouraging unsustainable use of wild seed and juveniles

All forms of CBA need to be evaluated in light of their social and economic viability, the wise use of fishery resources and their environmental impact as a whole. Greater efforts must be made to produce seed in hatcheries and make them available, especially to small-scale farmers. More efforts are needed in terms of research, investment and capacity building, and to ensure that continuing seed and broodstock fisheries are managed sustainably and through implementation of EAF.

Discouraging unsustainable use of fish for aquaculture feeds

National and local institutions and the aquaculture industry as a whole must consider the broader scale impacts of aquaculture on fisheries through the collection of fish for direct feed to aquaculture and the use of fishmeal and fish oil in feeds (Tacon *et al*., 2012; FAO, 2011). Efforts must be made to ensure that the fisheries that provide these inputs are managed according to EAF and that the aquaculture industry is moving towards the use of less fishery-dependent feeds, especially where fish can be used for direct human consumption.

Encouraging sustainable culture-based fisheries (CBF)

There is potential for improvement of impoverished fisheries species close to extinction and poverty alleviation through cooperative organization to enhance production from a common resource with few inputs: lakes and reservoirs, and seasonally flooded floodplains. Stocking of fish in areas amenable to fencing, especially those already partially enclosed by embankments or dykes, may result in yields significantly greater than those from wild fisheries. There appears to be great potential for developing these systems across large areas in both Asia and Africa, as there are many suitable sites; and entry costs for these systems may be low. Nevertheless as mentioned earlier, all forms of CBF must include some kind of risk assessment before taking place.

It is important to move beyond the focus on the fisheries objective and include the other ecological and social functions of the watershed or waterbody in the decision-making process of the stock enhancement programme. Although knowledge about specific ecosystems (of which fish stocks to be enhanced are a component) is less than perfect, precautionary approaches based on the best information about specific watershed/coastal zone and ecosystem processes should be considered and applied (Molony *et al*., 2003).

Measures to improve governance

Government institutions must pay closer attention to fisheries issues in any aquaculture activity (Figure 6), since, in general, the interdependency and interaction due to the use of common resources can be much stronger than with other sectors. Often there is a need for new institutional arrangements to manage common-pool aquatic resources and sustain investment in them, and this requires a review of the fisheries sector policy, considering both fishery and aquaculture. There should be a strong element of co-management where user organizations play an important role, frequently facilitated by various interest groups. In this regard, better and more effective communication systems and approaches are needed so that the aquafarmers can understand the fisheries issues and vice versa.

Government organizations have an important role to play in synergistic initiatives through creation of supportive institutional arrangements for research, extension and capacity building. Government institutions must also play their role in developing proper regulation and enforcement systems.

Establishing water basin/waterbody authorities to deal in a coordinated manner with both fisheries and aquaculture (as well as other users) can be very useful to resolve conflicts and to assess, monitor and take action on the added effect of many aquaculture farms and their interaction with fisheries.

Although catching and farming fish produce a similar end product, the process and activities reaching that end are different. Women and children have important roles to play as harvesters, processors and distributors of fish. As many areas promote aquaculture as an alternative to fishing, the roles of all stakeholders need to be considered to avoid displacing certain members of society and to ensure that new opportunities can be realized. A water basin authority can facilitate the interaction of stakeholders and a more participatory decision-making process with a more equitable distribution of resources.

Clearly, there is a need for monitoring and management on a system-wide basis to maintain the health of aquatic ecosystems and to implement corrective measures when needed. Monitoring and enforcement of rules is a key element of any active management system for common-pool resources. This is also relevant when self-governance arrangements exist, since rule monitors (enforcers) must be accountable to the self-governing institutions. This is relatively easy to achieve in clearly bounded systems under the control of a single body, such as for small waterbodies (Garaway, Lorenzen and Chamsingh, 2001). Where this is not the case, however, governments have to play a greater role in monitoring and enforcement. This may lead to problems, unless government enforcers are also accountable to the self-governing institutions. Difficulties in enforcing rules are the most important cause for changes in community rules (Barbosa and Hartmann 1998). Monitoring and enforcement has to look carefully into the delicate and often complex aquaculture-fisheries interactions, and this requires aquaculture and fisheries authorities to work together, even though in many countries the two sectors are taking separate routes after aquaculture`s fast growth.

The establishment of national programmes and international cooperation for research activities dealing with the interaction between aquaculture and capture fisheries (including the social aspects) would be useful in both marine and freshwater environments. The possibility of developing pilot projects at the waterbody scale based on the improvement of positive interactions between aquaculture and capture fisheries should be considered.

Making the management system operational

Implementing a management system to deal with aquaculture-fisheries interactions in a specific location/geographic area needs an operational plan that outlines, in detail, what would need to be done by whom, by when, and where. This includes identifying new activities and actions that need to be implemented and those existing activities and actions that need to be changed, as well as other activities that may need little or no change. The operational plan must include the timing, the resources (human and monetary), the institutions and stakeholders that need to work together, and must consider the practicality or feasibility of the proposed management arrangements.

When the feasibility is confirmed, all proposed management actions and arrangements need to be incorporated into a formal fishery and aquaculture resources management plan which has an appropriate legal basis. This can require drafting legislation or regulations, but for local small-scale aquaculture and fishery activities, other less formal documentation may be applicable.

Monitoring, evaluation and review of performance is the “final” step in the adaptive management planning process. It is essential to ensure that adequate performance is being generated against current objectives but also that the fish production from aquaculture and fisheries is as expected by local communities and other stakeholders.

As explained above, planning the implementation of management measures/ actions can take place at a waterbody scale, for example, planning a new cage aquaculture development in a lake or coastal ecosystem. However, planning at the country level may also be needed; for example, in a country producing fishmeal for export and also for local aquaculture (e.g. Chile), the planning for better integration of fisheries and aquaculture may need to consider nutrient fluxes (in the fish feeds), and costs and benefits of exporting fishmeal versus using this for local aquaculture. It is possible that fishmeal produced and used by aquaculture in the country contributes to more livelihoods in terms of jobs and income (added value) than fishmeal that is merely exported. Planning of an increased fish output by means of CBF and stock enhancement also may require whole-country planning, or even broader regional planning, if international watersheds are involved.

Using the ecosystem approach to facilitate implementation of the Bangkok Declaration

The issues identified in this review are especially relevant in the achievement of two objectives of aquaculture development as stated in the Bangkok Declaration (NACA/FAO, 2001):

- achieving its full potential as a food-producing activity that makes a net contribution to global food availability, household food security, economic growth, trade and improved standards of living; and
- as an integral component of the development, aquaculture shall contribute towards the sustainable livelihood of the poorer sectors of community, the promotion of human development and the enhancement of social wellbeing.

Additionally, the Bangkok Declaration stated that no activity should jeopardize the others, and that the use of technology and observation of the FAO *Code of Conduct for Responsible Fisheries* (FAO, 1995) were meant for the harmonious coexistence that underlies the principles of sustainable development.

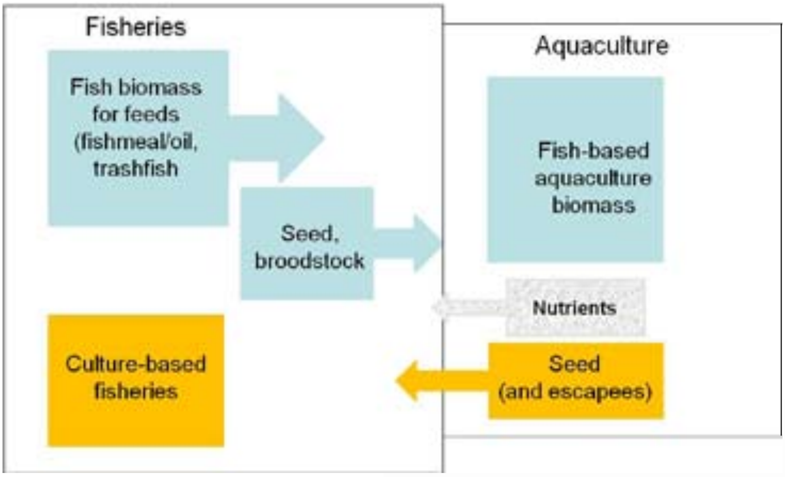
The ecosystem approach to aquaculture (EAA) can contribute to the achievement of the Bangkok Declaration commitments and to the FAO *Code of Conduct for Responsible Fisheries* through improvement of environmental and social sustainability by efficient use of resources, efficient production methodology, minimizing of unwanted outputs, improved income and equitable sharing of benefits. The EAA also facilitates integrated coastal zone development, while reducing conflicts with other sectors and coastal communities. In the present case, aquaculture development should minimize negative impacts on fisheries while enhancing potential contributions to this subsector and better integration of fish production.

In the long run, all significant commercial seafood supplies and non-food fish will come from one of three sources: i) fish farms/aquaculture; ii) aquaculture-enhanced fisheries or iii) fisheries that adopt efficient management systems. The first two pose challenges to aquaculture and require emphasizing the synergies and complementarities between fisheries and aquaculture, including institutional, social, economic, environmental and biotechnological aspects. Acknowledgement of these interactions offers opportunities for sectoral development, for increasing food security, reducing poverty and improving rural livelihoods. The two subsectors need to form partnerships, as both are strongly linked (Figure 7), both depend on healthy aquatic environments and both are impacted by other development activities. For example, as mentioned above, in the next decades, CBF will likely play a much greater role in sustaining and increasing capture fisheries yield for ultimate public good, including achieving conservation objectives. Therefore, it is important to analyze the present status of CBF and stock enhancement, comprehensively assess the impacts of the activities, and identify constraints and ways to improve their ecological, economic and socio-economic benefits by implementing an ecosystem approach to the overall fish production. It is also necessary to improve our understanding on the potential and actual environmental impacts of stocking and escapees worldwide beyond salmon!

Environmental degradation, climate change and overfishing will continue to impact the wild fisheries resource in the coming years, although efforts can be made to mitigate the impacts. Aquaculture`s reliance on fisheries for feeds will become increasingly challenging and less sustainable (Tacon *et al*., 2012).

Joint use of the environment and sustainable sharing of resources to the ultimate benefit of communities require that individual action not be treated in isolation, but as part of a much larger entire waterbody/hydrological system. This approach necessitates an understanding and awareness of the intricate interactions that make it sustainable. The strategy must unambiguously identify the roles of all stakeholders, assigning responsibilities and benefits, and in most cases revolve around the watershed, waterbody or relevant coastal zone as the geographic area of delimitation of actions and management.

FIGURE 7
The close connection between fisheries and aquaculture



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