World Bank Regional Agricultural Pollution Study

Aquaculture Pollution:

An Overview of Issues with a Focus on China, Vietnam, and the Philippines

2017

WORLD BANK GROUP

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ABBREVIATIONS

BFAR	Bureau of Fisheries and Aquatic Resources
BMP	Better Management Practice
CCRF	Code of Conduct for Responsible Fisheries
COP	Code of Practice
DENR	Department of Environment and Natural Resources
DILG	Department of Interior and Local Government
EAA	Ecosystem Approach to Aquaculture
eFCR	Economic Food Conversion Rate
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
FAO	Food and Agriculture Organization
FCR	Food Conversion Rate
IEE	Initial Environmental Examination
IIA	Integrated Irrigated Aquaculture
IMTA	Integrated Multi-trophic Aquaculture
ISA	Infectious Salmon Anaemia
PNP	Philippines National Police
SEA	Strategic Environmental Assessment
TCP	Technical Cooperation Program

FOREWORD

Between July 2015 and December 2016, the World Bank conducted a regional study of agricultural pollution in East Asia with a focus on China, Vietnam, and the Philippines, in cooperation with each country's ministry of agriculture. This effort aimed to provide a broad overview of agricultural pollution associated with farming at the regional and national levels: its magnitude, impacts, and drivers, and what is being done about them. It also sought to outline potential approaches to addressing these issues going forward. In doing so, the study examined how the structural transformation of the agricultural sector and the evolving nature of agricultural production are shaping agricultural pollution issues and mitigation opportunities. It also identified knowledge gaps, pointing to directions for future research. Ministries of agriculture and environment are the study's primary audience. Its secondary audience consists of development organizations, industry associations, and other actors with an interest in sustainable agriculture and environmental protection.

The study constitutes the totality of the work and includes multiple components, including national overviews of agricultural pollution for the three focus countries, thematic working papers, and an overall synthesis report. The present working paper provides background on aquaculture pollution issues in general and in the study countries in particular. It also presents an overview of mitigation approaches with examples from other countries.

SUMMARY

Aquaculture is probably the fastest-growing animal production sector in the Asia Pacific region. Aquaculture is predicted to continue increasing production by optimizing and intensifying existing aquaculture practices, increasing the number and type of farms, and exploring other environments.

Most modern fish culture involves more intensive input of nutrients in the form of feed, yet only a small proportion of these nutrients is actually converted into the target product; they can be largely lost to bacterial degradation. However, when compared with other livestock production, aquaculture has better feed conversion, and food conversion rates (FCRs) continue to improve. High levels of nutrients in effluent discharge to channels, rivers, or lakes may cause eutrophication and affect fisheries adversely, but in other cases, depending on dilution rates, effluents may be a beneficial addition of nutrients which boost natural productivity including fisheries.

Modern, intensive, land-based aquaculture systems can be divided into two types: open and closed systems. In open systems, such as fish culture in floating cages, water used to rear fish, from whatever source, is discharged (untreated) into the environment with its content of solids and nutrients. In closed systems, such as fish or shrimp culture in ponds, some part of the water is recycled after specific treatments to reduce the content of solids and dissolved nutrients.

The important fish farming waste components are nutrients (dissolved and particulate) resulting from the metabolism of fish food (including natural food in the case of filter feeders such as mussels and clams), uneaten food, pseudofeces (in the case of filter feeders), escapees of farmed fish affecting the genetics of wild fisheries species, and residues of disease or parasite treatment chemicals.

The environmental impact can be lessened by improved location of farms, improved farm management, or by physical and/or biological treatment of the effluent.

China is the leading country in Aquaculture production and Vietnam and the Philippines are in the top 10. Aquaculture continues to grow in China and Vietnam but is presently declining in the Philippines because of reduction in seaweed production.

Key issues contributing to increasing pollution include:

- Increasing production from aquaculture (new areas, new farms, bigger farms) with poor planning;
- Increasing production intensity (increasing use of feeds, increasing productivity);
- Increasing use of improved genetic strains and exotic species (potential impact to wild fisheries);
- Clustering of small-scale producers leading to poor water quality locally and more widespread environmental impacts; and
- Emergence of new diseases resulting in higher use of medication that can enter the environment.

Potential measures for mitigation of pollution

Public sector approaches

- Appropriate and specific aquaculture policies, strategies, regulations, legislation, and management plans
- Stronger adoption and implementation of the Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries (CCRF)
- Adoption of the Ecosystem Approach to Aquaculture (EAA) Strategy for planning, management, monitoring, and control
- Zoning for aquaculture space allocation based on suitable areas, carrying capacity of the ecosystem, planning and management for disease prevention and treatment, and environmental control
- Use of Strategic Environmental Assessment (SEA) for identification of potential environmental issues at the larger zone scale also considering other users/polluters of the coastal zones and waterways
- Use of carrying capacity estimation to limit farm and zone production
- Improved farm permitting, licenses, and registration to monitor and control aquaculture development
- More widespread use of the Environmental Impact Assessment (EIA) or Initial Environmental Examination (IEE) for clusters of small-scale farms to limit environmental impact
- Development and implementation of farm-level Environmental Management Plan (EMP)
- Environmental monitoring audit undertaken by government departments to monitor aquaculture impact

Public-private approaches

- Area management of aquaculture by clusters of farmers for management of disease and environment
- Development of aquaculture/mariculture parks for controlled sustainable development of small-scale aquaculture
- Use of Integrated Multi-trophic Aquaculture (IMTA), including integrated landscape planning and Integrated Irrigated Aquaculture (IIA) to utilize nutrient output from intensive aquaculture
- Use of algal ponds and constructed wetlands to reduce nutrient levels in aquaculture effluents
- Regular environmental monitoring to ensure that impacts remain within acceptable levels
- Better Management Practices (BMPs)

- Improved feed formulation and feeding strategy to reduce the feed conversion ratio and reduce nutrient losses

- Use appropriate incentives to improve management and environmental performance; for example, clusters certification, reduce value chain length with greater income for smaller farmers, and appropriate consumer awareness of better environmental performance

Farm-level approaches

- Reduction of water exchange and water-use efficiency

- Treatment of farm effluents with sedimentation or mechanical filtration

AQUACULTURE SECTOR TRENDS AND POLLUTION CHALLENGES

Demand for seafood continues to increase due to increasing population and increasing development of the middle classes. However, over 75 percent of the world's fisheries are considered fully exploited or overexploited, leaving little room for increased harvest from wild stocks. Therefore, future fish supplies will be dominated by aquaculture systems through increased growth in supply and production efficiency improvement through expansion and intensification. This chapter gives a brief overview of trends and structural changes in the aquaculture sector, and some of the pollution challenges that have been associated with these, both within and outside the region.

1. Aquaculture sector trends and structural changes

World food fish aquaculture production expanded at an average annual rate of 6.2 percent during the period 2000–2012 (down from 9.5 percent in 1990–2000), from 32.4 million metric tons to 66.6 million tons of food fish1 (US$137.7 billion) and 23.8 million tons of aquatic algae (mostly seaweeds, US$6.4 billion).

The annual growth rate in China, the largest aquaculture producer, averaged 5.5 percent in 2000–2012 (12.7 percent in 1990–2000). Excluding China,

1 The term 'food fish' includes finfish, crustaceans, mollusks, amphibians, freshwater turtles, and other aquatic animals (such as sea cucumbers, sea urchins, sea squirts, and edible jellyfish) produced as food for human consumption.

production in the rest of Asia grew by 8.2 percent per year (4.8 percent in 1990–2000). The 15 main producer countries accounted for 92.7 percent of all farmed food fish production in 2012, which included seven countries from Southeast Asia (China, Vietnam, Indonesia, Thailand, Myanmar, the Philippines, and the Republic of Korea). Any growth in aquaculture production will involve an expansion of cultivated areas, an increase in culture intensity, a higher density of aquaculture installations, and the increased use of feeds, fertilizer, and chemical inputs, as well as increased land and water use. Excess feed and fish wastes (solids, ammonia) cause organic enrichment of the environment, with effects on pelagic/benthic chemistry, community structure, and so on.

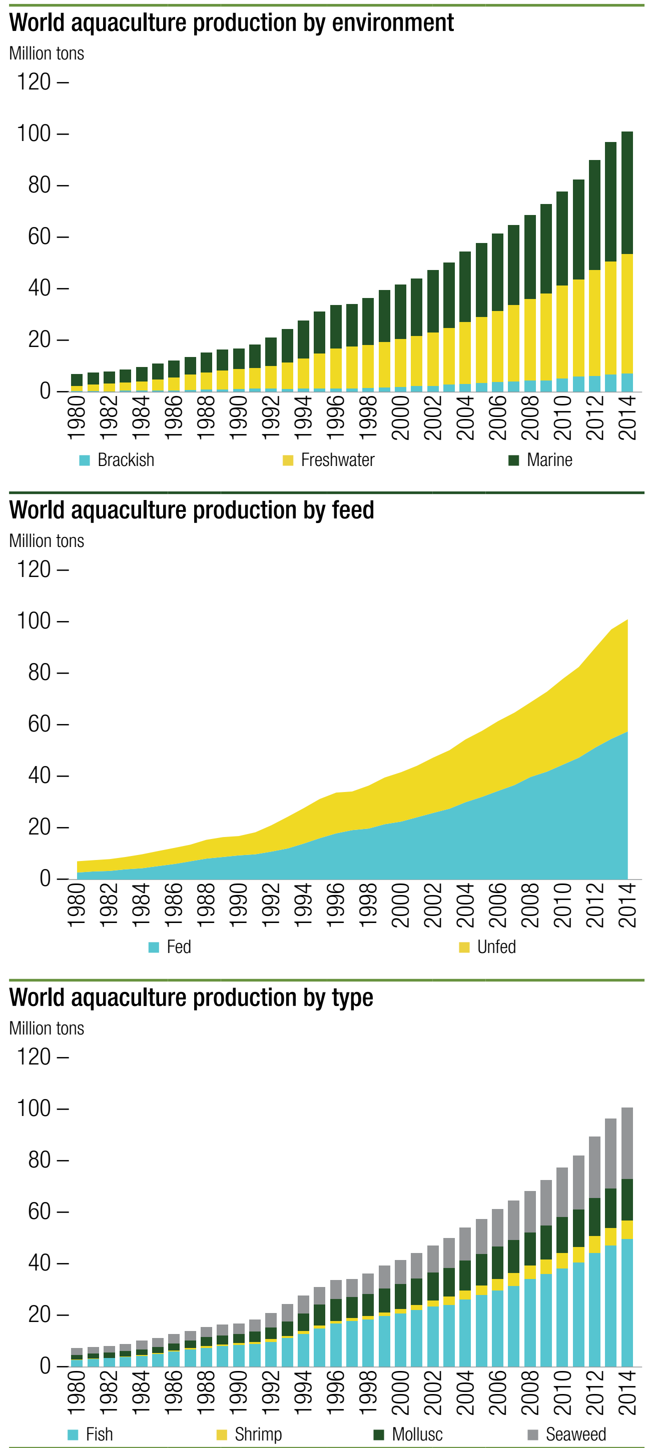
Aquaculture is expanding with the increase in number of farms, establishment of farms in new geographical areas, increasing farms size, increasing intensity of cultivation (stocking density), and increasing farm productivity (for example, improved survival).

When seaweed culture is included in the figures of aquaculture production in brackish and marine waters, production continues to dominate world production and this is predicted to continue as freshwater is a valuable and limited resource with increasing demand from other sectors. In addition, the technology for offshore culture systems continues to improve.

In addition to increasing production, there are some changes in farming environment:

- **Aquaculture in freshwater.** Of the 66.6 million tons of farmed food fish produced in 2012, two-thirds (44.2 million tons) were finfish species grown from inland aquaculture. The rapid growth in inland aquaculture of finfish reflects the fact that it is a relatively easy-to-achieve type of aquaculture in developing countries when compared with mariculture where the hatchery production of fry is much more complex. Aquaculture in freshwater now accounts for 57.9 percent of farmed food fish production globally.

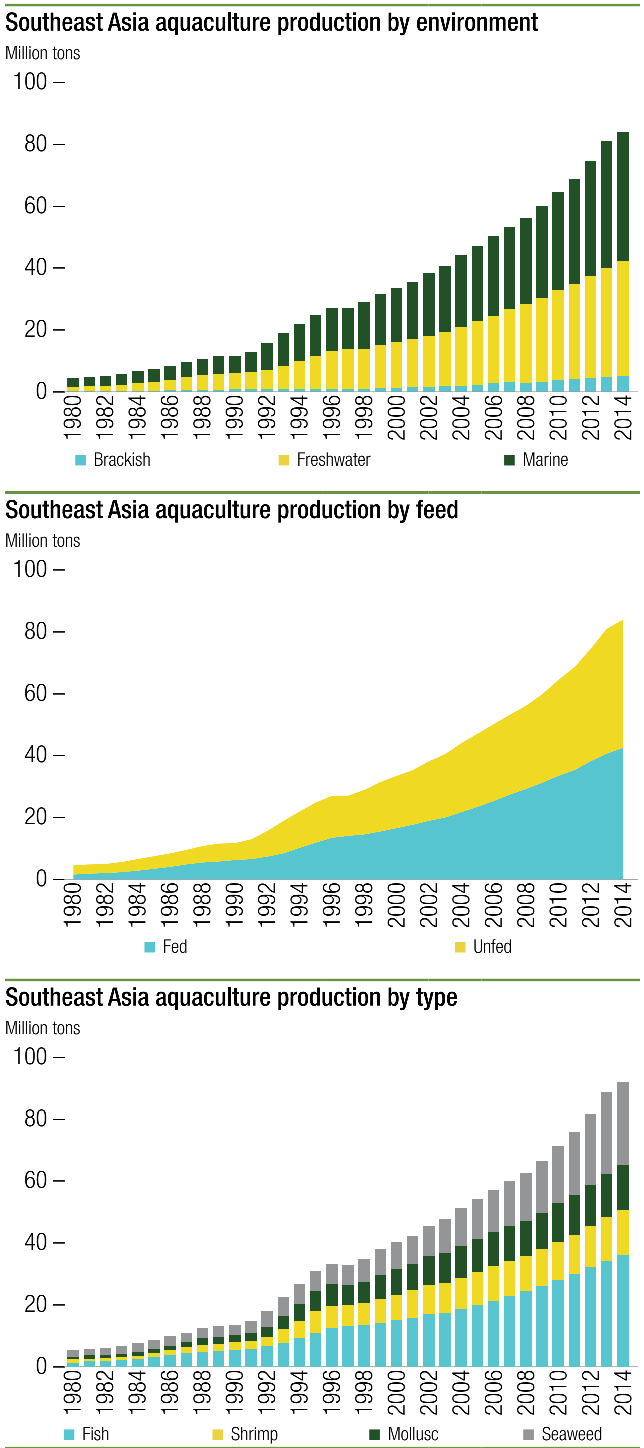
Figure 1. Analysis of world aquaculture production



Source: FAO FishStatJ.

- **Aquaculture in marine and brackish water.** Although finfish species grown from mariculture was 5.6 million tons, representing only 12.6 percent of the total farmed finfish production by volume, their value

Figure 2. Analysis of aquaculture production from Southeast Asia



Source: FAO FIshStatJ.

(US$23.5 billion) represents 26.9 percent of the total value of all farmed finfish species. This is because finfish grown from mariculture include a large proportion of carnivorous species, such as Atlantic salmon, trout, groupers, and shrimp, that are higher in market demand and price than most freshwater-farmed finfish.

The culture of fish also continues to dominate world production (49 percent of world production) but shrimp and seaweed production are growing faster (up from 4.2 percent to 7 percent and 22.3 percent to 27.4 percent of world production from 2000 to 2014, respectively (FAO 2014).

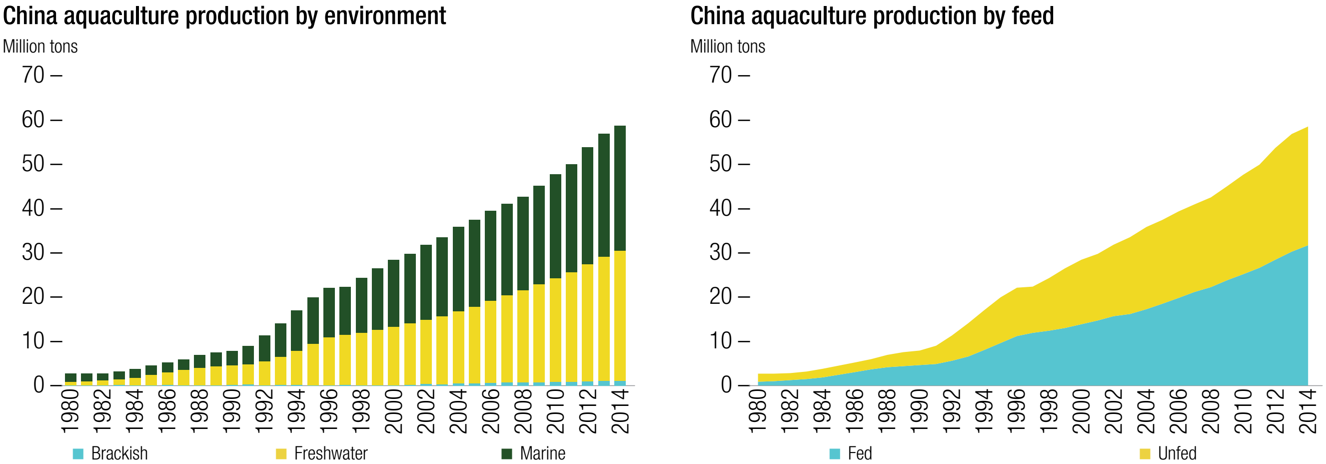
As Southeast Asia and China dominate world aquaculture production, the trends follow world trends closely in terms of environment, feed, and species.

For the three focus countries, China, Vietnam, and the Philippines, there are some major differences in production and trends. Trends differ on the water source, species that are produced, and whether the species are fed or not.

- **China.** China is highly diversified in terms of aquaculture species and farming systems, and its finfish culture in freshwater forms the staple supply of food fish for its domestic market. Freshwater production is dominated by fish production, brackish water production by shrimps, and marine production by the production of bivalves and seaweed. Its finfish mariculture subsector, especially marine cage culture, is comparatively weak, with only about 38 percent (395,000 tons) being produced in marine cages. Between 2000 and 2012, farmed seaweed production almost doubled to 12,832,060 tons (53.97 percent of global production), with the development of high-yield strains of major species playing an important role. Seaweed farming has long been promoted in China in areas of marine cage culture for bio extraction of nutrients in the seawater as a way to reduce eutrophication and other nutrient impacts to the environment. Aquaculture based on feeding is increasing as farms intensify production and fish and shrimp production continues to increase.

With the development of intensive marine mariculture, the impact of the industry on the ecosystem has become serious, and in turn

Figure 3. Analysis of aquaculture production from China



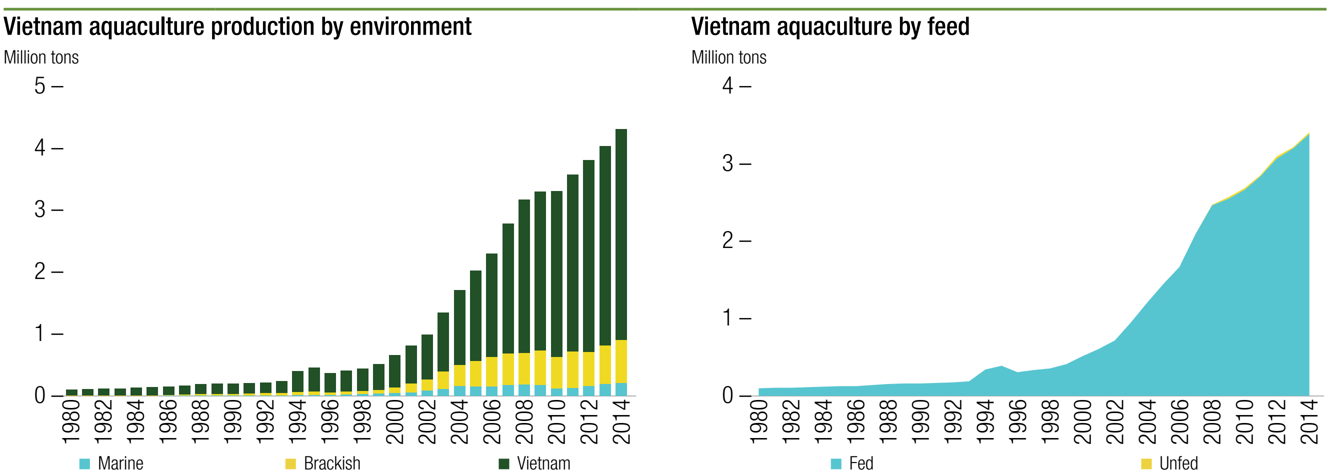
Source: FAO FIshStatJ.

the degraded environment has resulted in higher mortality of mariculture organisms. It was estimated by Cui et al. (2005) that waste nutrients discharged from mariculture activities along the Yellow Sea and Bohai Bay consisted of approximately 6,010 tons of nitrogen and 924 tons of phosphorus. These discharges accounted for 2.8 percent and 5.3 percent of total land-sourced pollutants in these areas, for nitrogen and phosphorus, respectively. This indicates that nutrient discharges by mariculture have reached a noticeable level in certain regions of China.

- **Vietnam.** In Vietnam, more than half of the finfish from inland aquaculture are *Pangasius* catfish produced in freshwater ponds and traded overseas. In addition, it has a large crustacean production subsector, including shrimps grown in brackish water and giant freshwater prawn. The growth rate of *Pangasius* catfish production has slowed in recent years due to lack of market demand. Also, the growth of prawn culture was set back by the outbreak of a new disease (Early Mortality Syndrome). In Vietnam, there is almost no production of bivalves and seaweed.

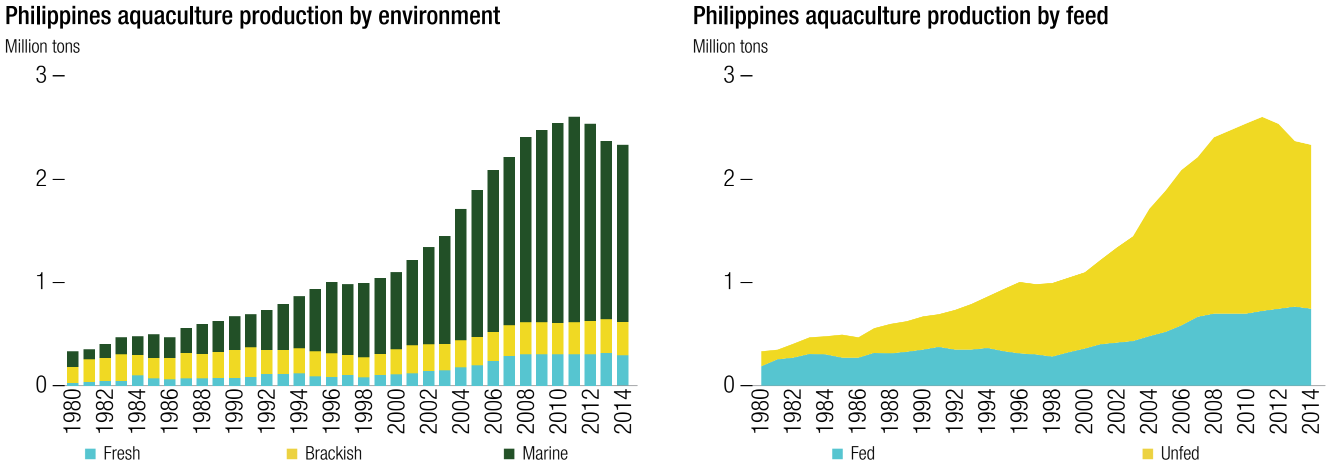
- **The Philippines.** In the Philippines, finfish production overshadows that of crustaceans and mollusks. The country produces more finfish from mariculture than freshwater aquaculture, and about one-fourth of the mariculture-

Figure 4. Analysis of aquaculture production from Vietnam



Source: FAO FIshStatJ.

Figure 5. Analysis of aquaculture production from the Philippines



Source: FAO FishStatJ.

produced finfish, mostly milkfish, are harvested from cages in marine and brackish water. Seaweed production has dropped during the last few years but the Philippines still produced 1,751,071 tons of aquatic plants in 2012, which was 7.36 percent of global production.

The past 20 years have seen Asian aquaculture evolve from a traditional practice to a science-based activity and grow into a significant food production sector, contributing more to national economies and providing better livelihoods for rural and farming families. Aquaculture is still relatively small in comparison with crop and livestock production but is now larger than wild fisheries and world beef production. It has since matured into a better-organized economic sector, characterized by more state patronage and also a stronger private sector participation in most parts of Asia.

Other emerging trends that could affect increasing pollution from aquaculture include:

- **Genetic improvement of strains.** Genetic improvement of aquaculture species in Asia is well developed for tilapias and carps and, more recently, for shrimp. This was initiated by donor-funded projects but is now continued by nationally funded projects and the private sector. However, escapees of improved strains could affect the wild stock genotypes, with consequent impacts on fitness and the size of wild populations.

- **Development of new species for culture.** The development of new species (particularly marine species) is a key aquaculture development strategy for several Asian countries, but progress is relatively slow as research and development funding is low and marine fish hatchery technology and methodology is not well developed.

- **Increased hatchery production of seed.** Although wild fry are still collected for some species, there is a greater hatchery production of seed for carps, tilapia, milkfish, freshwater prawn, and indigenous freshwater species. Much remains to be done for marine shrimp (particularly on brood stock development), grouper (especially mass seed production), and mangrove crab (also mass seed production). With increasing hatchery production of seed, there is less pressure on wild fisheries recruitment from the collection of seed from the wild.

- **Clustering of small-scale producers.** There is a trend within the development of small-scale producers in Asia that farms are established in suitable areas such as sheltered bays and lakes for cages or large estuaries for shrimp pond farms, leading to the formation of large clusters of farms. This is primarily due to small-scale producers copying other successful producers and the lack of government control of licenses for new farms. Each individual farm does not cause significant pollution but the cumulative effect of large numbers of small farms can cause significant environmental impact, leading to algal blooms and fish kills and reduced productivity and profitability of farm operations.

- **Emergence of new diseases.** Shrimp diseases such as Early Mortality Syndrome and White Spot Syndrome Virus have caused significant economic losses, and the prevention and control of disease will remain an important issue. Many of the new diseases are also old, established diseases appearing in new geographic locations through poor biosecurity. Techniques for disease diagnosis, as well as products and methodologies for prevention and control, have only recently been developed and applied in the field, largely because of the occurrence of viral shrimp diseases. New diseases are treated by existing or new medication adding to the amount of medication used and released into the environment.

2. Aquaculture pollution challenges

Together with increased aquaculture production, there will also be increased pollution and impact on the environment. The pollutants are primarily:

- Dissolved nutrients—excretion of dissolved nutrients which can lead to localized eutrophication of water bodies;
- Particulate nutrients—feces and waste food settling on the seabed or pond floor causing changes in sediment chemistry and biology;
- Chemical pollution—antifoulants on boats and fish cage nets and medications and treatments; and
- Escapees—causing changes in the genotypes of wild fish populations and biodiversity.

Other impacts of aquaculture are:

- Physical structures such as cages, pens, ponds, and jetties along the coast;
- Visual/scenic, which may pose a problem for tourism;
- Changes in water flow and volume (for example, arising from friction of water passing through the nets of fish cages and fish pens);
- The use of 'trash fish' to feed fish specially in Asia, increasing pressure on coastal fisheries for aquaculture feed; and
- Increasing use of wild larvae for shrimp culture, which is booming again in some countries in the region.

The metabolic activity involved in converting fish feed to fish flesh produces waste products. These consist of suspended solids and dissolved nutrients. Suspended solids amount to approximately 25 percent of the feed used on a dry matter basis. Methods for the relatively simple removal of suspended solids are applicable to both flow-through and recirculation farms. Suspended solids from flow-through fish farms are relatively low and flow volumes are relatively high. In a fish farm, suspended solids and dissolved nutrients originate from:

- Uneaten feed;
- Fish metabolism producing feces and pseudofeces in the case of filter feeders;
- Solids carried into the farm with the flow from the external water source; and
- Growth of microalgae and bacteria.

There are a number of factors affecting the level of pollution from aquaculture mainly due to the intensity of production, the species being cultured, the culture system, and the planning and management of the farms.

- **Aquaculture that involves the addition of feed or fertilizer, for example, fish farmed in cages and shrimp farmed in ponds.** With this type of aquaculture, nutrients are added to the culture system in the form of feed or fertilizer. These nutrients are not fully utilized by the production and the remaining nutrients are added into the water system. Due to the continued intensification of aquaculture (higher productivity per unit area) where feeds are given, the share of fed species in total farmed food fish production increased further from 66.5 percent in 2010 to 69.2 percent in 2012. This trend is expected to continue, resulting in increased nutrient release to the environment. However, with improved management of the feeding, increased production is possible without significantly increasing waste and while minimizing environmental impacts.

- **Aquaculture of species that are not fed but extract nutrients from the environment, such as extensive culture of finfish, seaweed, and mollusk culture.** In 2012, global production of non-fed species from aquaculture was 20.5 million tons, including 7.1 million tons of filter-feeding carps and 13.4 million tons of bivalves and the harvesting of 23.8 million tons (wet weight) of aquatic plants. China and Indonesia dominate seaweed production, accounting for 81.4 percent of the total production. World production of farmed seaweeds more than doubled from 2000 to 2012; however, non-fed aquaculture remains lower than fed aquaculture.

- **Aquaculture systems that are open systems, such as pen or cage culture of fish, where water passes freely through the cage nets and unused nutrients are released directly into the water body** with the distribution of the nutrients highly influenced by the hydrodynamics of the site location.

- **Aquaculture systems that are semi-closed such as fish and shrimp pond culture.** In pond culture, much of the excess nutrients are either utilized by primary production and are subsequently eaten by the fish or accumulate on the pond bottom as sediments. However, nutrients are only released into the environment during water exchange and at harvest time when pond water effluent is released to the environment as a point source release into the river, estuary, or sea.

As the trend in aquaculture development is to produce more intensively and produce in open culture systems such as fish cage culture, there is a move from low-waste nutrient output systems to higher-waste nutrient output systems that the environment needs to assimilate.

At the farm level, the production rate of dissolved and suspended solids within a fish farm is affected by a range of factors, including feed quality, feeding rate, feeding method, water exchange rate, pond and tank hydrology, fish stocking density, dissolved oxygen level, efficiency of farm management, and the skills of personnel. Climatic factors can also influence appetite and feeding rate through changes in temperature (especially extreme temperatures), heavy rainfall affecting water pH and salinity, and so on. Climate change therefore could affect the efficiency of nutrient uptake in the future.

SOURCES AND IMPACTS OF AQUACULTURE POLLUTION

1. Overview of major sources and impacts of pollution

Pollution can cover a range of impacts such as nutrient, genetic, chemical, disease, invasive species, and so on. The following aquaculture polluting outputs are considered, including release of nutrients, diseases, medications and chemicals, and escapees.

Nutrients are added in the form of juveniles, fertilizers, and feed to culture systems. Not all the nutrients are absorbed by the growing fish or shrimp. Soluble nutrients coming from the digestion processes 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 fecal material can also accumulate below culture cages and in the outflows of aquaculture facilities.

Impacts from eutrophication-related pollution (nitrogen, phosphorus, and carbon outputs)

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 through the decomposition of waste solids).

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, so its addition will dictate the amount of primary production (algal growth). In marine environments, nitrogen is typically the limiting nutrient, so its addition will do likewise.

High-nutrient concentrations can 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.

Impacts on water column and benthic community

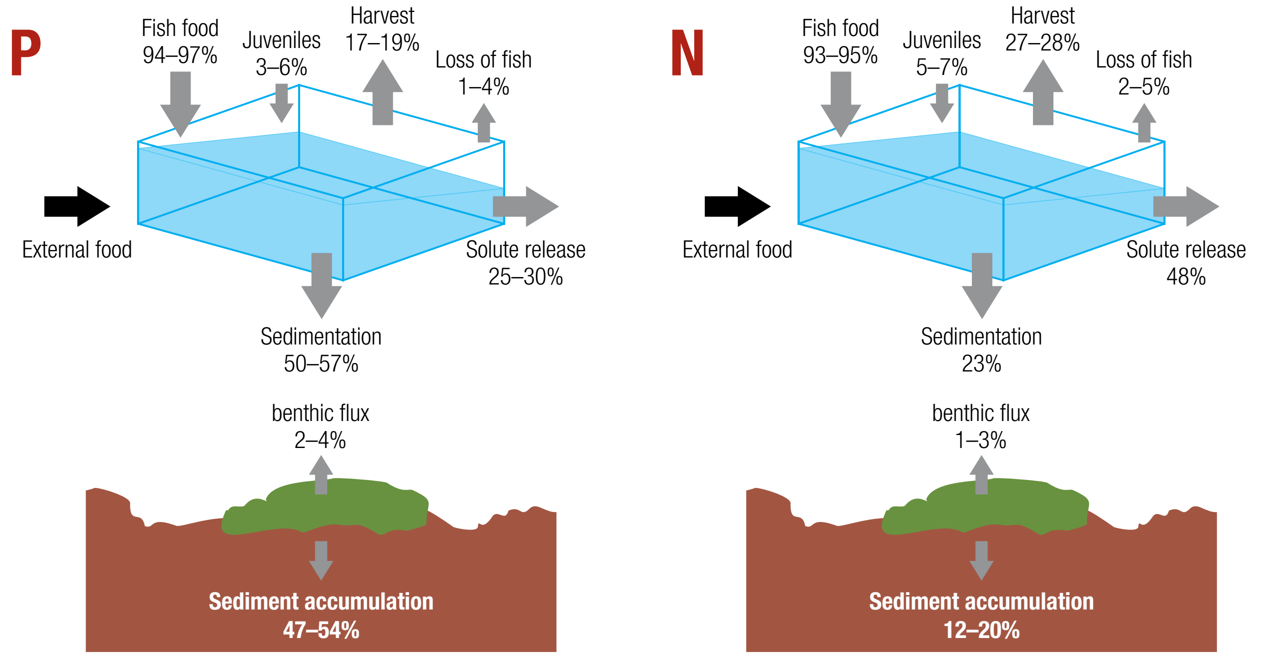
Organic enrichment of the seabed is the most widely known effect of fish farming globally. This can impact benthic (for example seagrasses) and other sensitive habitats (for example, corals) close to the farm. However, in many cases, additional nutrients can also provide more food and enhance local fisheries. Often, particulate material including uneaten feeds and feaces become direct food for other aquatic animals; this is common around and under fish cages that becomes an "'attraction'" for all sorts of aquatic animals. In such cases, the potential waste becomes new biomass and as mentioned it could have a positive impact on local fish stocks.

The accumulation of nutrient solid waste will depend on the local currents and depth. There is some benthic flux where nutrients are released back into the water column from the sediments. A typical nutrient balance for a fish cage farm is given below.

Impacts from main chemicals (medication, antibiotics, and pesticides)

Aquaculture practices, particularly intensive forms, sometimes require the use of therapeutics for controlling diseases. Therapeutics include agents used for the effective treatment and/or prevention of disease, and include antimicrobials (including antibiotics), antiparasitics, fungicides, biologics, hormones,

Figure 6. Nutrient balance from cage farming



Source: Holby and Hall 1991.

chemicals, solutions, and compounds; not all of these may be used at any particular aquaculture site. Therapeutics and other chemicals can be administered to fish through medicated feed or through external treatments. Higher-intensity production tends to be more prone to disease outbreak. Disease risk can be reduced by implementing effective biosecurity measures.

Therapeutics 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 therapeutic. This is undesirable especially in the case of antibiotics, 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.

For example, cultured salmon are susceptible to epidemics of parasitic diseases. Sea lice are the most prevalent ectoparasites of cultured salmon and have been a problem for salmon aquaculture industries in Norway, Chile, and so on. Parasiticides are used in the treatment of sea lice infestations and are subsequently released to the aquatic environment and may have impacts on other aquatic organisms and their habitat. These compounds are lethal, especially to aquatic invertebrates. Concerns with their use are mainly with the potential of these compounds to affect non-target organisms.

The use of therapeutics, especially antibiotics, is now strongly regulated in many countries, again due to the strict requirements of many nations, including importing markets. Antibiotic use has diminished significantly in some countries after the development of fish vaccines. However, the development and use of vaccines in Asia has been slow and there is still a dependence on antibiotic use although there are now strict control checks on antibiotic residues in fish when importing to the U.S. and the European Union.

Impacts from other sources of pollution

Antifoulants

Copper and zinc have been measured in sediments near aquaculture sites at concentrations in excess of sediment quality guidelines. These elements can be lethal to aquatic biota and persist in sediments. Copper-based antifouling paints are sometimes applied to cages and nets to prevent the growth of attached marine organisms on them. The buildup of these organisms ('epibiota') reduces the water flow through the cages and decreases dissolved oxygen. The rate of release of chemicals from the paint is affected by the toxic agent, temperature, water current speed, and physical location of the structure. The active ingredients in these paints will leach out into the water and may exert toxic effects on non-target local marine life both in the water column and in the sediments below the cages, where the chemicals tend to accumulate. Currently, copper-based paints are the most prevalent antifoulant in use (Burridge et al. 2010). Organisms require essential elements such as copper for physiological processes and growth. As such, they are considered normal constituents in the ecosystem in both soil and water. They cannot be degraded and can accumulate and persist in sediments. The amount of copper and zinc required for normal metabolism is small and, for this reason, they are considered micronutrients. However, they can be detrimental to organisms if concentrations exceed those required by the organism and can bioaccumulate, which is dangerous if they are organisms such as bivalves that are to be sold for human consumption. New alternative antifoulants are being developed using silicone or changing the physical properties of the netting.

Genetic pollution

Escapees of juvenile or adult fish are a constant possibility if operational or technical failures occur at fish farms. In some cases, due to the large numerical imbalances of caged compared to wild populations, escapees raise important concerns of ecological and

Table 1. Key pollutants, level of nutrient impact, and scale of impact on culture system/species

Culture System/Species	Key Pollutant	Nutrient Impact	Local Scale	Medium Scale	Wide Scale
Seaweed culture	—	+++	+++	++	+
Bivalve culture	—	+++	+++	++	+
Small-scale freshwater Fish cage culture	P	- -	- -	-	—
Multiple small-scale freshwater farms	P	- - -	- - -	--	-
Small-scale marine fish cage culture	N	-	—	—	—
Multiple small-scale marine fish cage farms	N	- - -	- - -	-	—
Industrial marine fish cage culture	N	- - -	- - -	-	—
Freshwater fish pond culture	P	- -	- -	-	—
Shrimp pond culture	N	- -	-	—	—

Note: + positive impact; - negative impact; P = phosphorus; N = nitrogen.

genetic impacts. Such impacts are very similar to those described in the case of stock enhancement and culture-based fisheries.

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. The potential ecological risks from escaped farmed fish is that 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, which has been selected to perform well in farm environments. In the long run, this may change the wild stock to the extent that it no longer is able to survive well in its original environment. The use of top-level predator alien species can also become invasive species in certain environments; for example, brown trout introduced in South Africa have eliminated some local species. In Thailand, the introduction of the North African catfish led to routinely hybridizing with native catfish, with the result that native clariid catfish are becoming a threatened species.

Impacts of pollutants on different scales

Calculating the nutrient input to water bodies from aquaculture is part of the calculation for sustainable aquaculture carrying capacity within the water body. Carrying capacity can be estimated at the farm level and is sometimes used to limit the size of production license granted, for example, in Scotland and Norway, or on a broader scale such as a lake, bay, or watershed (Ross et al 2013). Nutrient impact in marine waters tends to be localized and is quickly diluted by tidal flushing compared with freshwater culture systems, where impacts can be on the water body as a whole and where there is a relatively long water residence time as in dams and lakes.

Table 1 summarizes the key pollutants, the level of the nutrient impact, and the scales at which the impacts occur.

2. Case studies

The following case studies have been chosen to illustrate the scale of impacts that can occur in freshwater (cages and ponds) and marine (waters cages) at different scales (small lake, large estuary, regional sea). They also illustrate the cumulative impacts on the environment form clusters of small-scale farms.

Figure 7. Fish cages in Taal Lake, the Philippines

Source: G Christiansen.

Case Study 1. Taal Lake, the Philippines

Taal Lake is the third-largest lake in the Philippines. It covers a water surface area of 24,256.4 ha. It is a relatively deep lake with the deepest portion as much as 180 m and an average depth of about 65 m. The lake has a relatively small watershed of about 68,373 ha, giving a water residence time of approximately 20 years. The lake provides livelihood to a large number of sustenance fishermen and supplies fishery products to the lakeshore inhabitants. During the 2000s, the exploitation of the lake by fish cage culture intensified rapidly, leading to poor water quality and increasing frequency of algal blooms, hypoxia, and fish kills. In 2006, the Norad-funded Environmental Monitoring and Modelling of Aquaculture Project undertook an estimate of fish farm number by aerial photography and fish farm production by interviews. The survey revealed that there were 9,692 fish cages of which 89 percent were operational (8,626) and 11 percent unoperational or empty (1,066).

The total operational fish cages have a volume of 7,248,380 m^3 and are stocked with tilapia (99.5 percent) and milkfish. The annual aquaculture production from the lake was estimated at 112,408 tons of fish (4.8 tons of fish per ha) with an average of 529 tons of fish feed fed each day. Using the Legovic box model for carrying capacity estimation, it was calculated that the estimated production was 3.7 times the sustainable carrying capacity.

There are 11 municipalities surrounding the lake, each with different strategies for licencing of fish farms. In addition, there was very poor control of illegal or unlicensed fish cages. A task force was set up in 2008 to start dismantling illegal cages to achieve a total of 8,000 fish cages. In 2011, the Provincial Government of Batangas in collaboration with BFAR, DENR, DILG, PNP, Coast Guard, Tanggol Kalikasan, Taal Lake's coastal local government units, and local residents began dismantling a further 1,300 illegal fish cages with a target to reduce the number to 6,000 fish cages only (Palerud et al.).

It is essential to undertake aquaculture carrying capacity estimation in freshwater lakes and have strong governance for registration and licencing of farms to avoid heavy impact on water quality.

Figure 8. *Pangasius* catfish ponds along the banks of the Mekong River, Vietnam

Source: Google Earth.

Case Study 2. *Pangasius* catfish pond farming in Vietnam

De Silva et al. (2010) undertook a study to estimate nitrogen and phosphorus discharged to the environment from the striped catfish (*Pangasianodon hypophthalmus*) farming sector in the Mekong, South Vietnam. The sector accounted for 687,000 tons of the production in 2007 and 1,094,879 tons in 2008, with over 95 percent of the produce destined for export to over 100 countries. Commercial and farm-made feeds are used in catfish farming, with the former being more predominant currently. Nitrogen discharge levels were similar for commercial feeds (median 46.0 kg/t fish) and farm-made feeds (median 46.8 kg/t fish), while phosphorus discharge levels for commercial feeds (median 14.4 kg/t fish) were considerably lower than for farm-made feeds (median 18.4 kg/t fish).

Based on the median nutrient discharge levels for commercial feeds, it was estimated that striped catfish production in the Mekong Delta discharged 31,602 tons nitrogen and 9,893 tons phosphorus in 2007 and 50,364 tons nitrogen and 15,766 tons phosphorus in 2008. However, the amount of nutrients returned directly to the Mekong River may be substantially less than this as a significant proportion of the water used for catfish farming is used to fertilise rice fields and sludge from the bottom of the pond is used for fertilising orchards. Striped catfish farming in the Mekong Delta compared favorably with other cultured species, irrespective of the type of feed used, when the total amounts of nitrogen and phosphorus discharged in the production of a ton of produce was estimated (De Silva et al. 2010).

Even with highly intensive aquaculture production on a large scale, impacts can be controlled by good planning and by implementing mitigation measures to reduce impacts.

Case Study 3. Nutrient loading of large water bodies by aquaculture

Mediterranean fish farming has grown exponentially during the last 20 years. Although there is evidence of the localized sediment impact around fish farms, there are concerns that the release of solute wastes from aquaculture might impact larger scales in the ecosystem by changing the nutrient load. Karakassis et al. 2005 made estimates for the total quantities of the nutrient pool in the Mediterranean as well as the total atmospheric and terrestrial inputs. After combining information from various sources on waste production and on nutrient loads, it was concluded that the overall nitrogen and phosphorus waste from fish farms in the Mediterranean represents less than 5 percent of the total annual anthropogenic discharge, and the overall annual increase in phosphorus and nitrogen pools in the Mediterranean, under a production rate of 150,000 tons, is less than 0.01 percent. The proportion of fish farming discharged nutrients was slightly higher in the eastern Mediterranean.

A simple model was used to assess the long-term effects of nutrients released from various sources considering the water renewal rate in the Mediterranean. Karakassis et al. (2005) concluded that, in the long term, fish farm waste could cause a 1 percent increase in nutrient concentrations in contrast to other anthropogenic activities which might double the Mediterranean nutrient pool.

Aquaculture impacts are relatively low on the larger scale when compared to other sources of pollution. In fact, sometimes they can be beneficial with the example of higher dissolved nutrients supporting higher plankton and zooplankton production which in turn increases wild fisheries production (Karakassis et al. 2005).

3. Lessons learned on what to avoid

There are certain practices undertaken by farmers that contribute to polluting impacts from aquaculture. These practices are generally due to a lack of knowledge or economic decisions taken to save money.

Poor aquaculture planning and farm siting

Poor planning and siting of fish farms can lead to both impacts on the environment and cause continuous production and management problems for the farmer. In the past, a large number of shrimp ponds in Southeast Asia were developed in mangrove areas which reduced coastal protection as well as affected coastal fisheries by reducing the natural habitat for wild juveniles. Other examples include the siting of shrimp pond effluent canals and fish cages in coral reefs where the high suspended sediment levels smother the reef and siting of farms in areas where there is insufficient water supply or water with low quality affecting farm productivity.

Figure 9. Shrimp farm cut into mangrove forests, Malaysia

Source: Shrimp News.

The lack of appropriate planning and zoning is the main reason for poor site selection.

Cumulative impact from clusters of farms (Indonesia/the Philippines/Chile)

Individual small-scale farms do not generally cause environmental impact; however, large clusters of small-scale farms can cause significant cumulative impact.

Impact can be from the friction of all the netting from the fish pens in Dagupan that leads to restricted water flow and low oxygen to the vast number of fish cages in Waduk Jangari Dam in Indonesia that has a major impact on the water quality.

Again, carrying capacity estimation together with strict control of the number of farms is necessary to control this type of over development.

Use of poor quality feeds and "trash fish"

In Asia, a proportion of small- and medium-scale farmers use lower cost homemade feeds, which are of low quality and sometimes a biosecurity risk. These feeds, which the farmers perceive as low cost, generally have low binding properties so that the feed crumbles as soon as it is in the water and either dissolves into the water and/or settles to the bottom before it is eaten. Some feed manufacturers offer favorable credit terms to encourage farmers to buy their feed; however, the feeds are not always the ones that give the best FCR or economic food conversion rate (eFCR).

Other farmers still use fisheries bycatch, low-quality fish, or 'trash fish' which are typically small fish which are either the juveniles of large edible fish or other species that are unpalatable. FCR of trash fish to farmed fish can range between 8:1 and 2:1, which is inefficient. There is also a risk of transfer of disease from the trash fish to the farmed fish.

However, there is an increasing trend to move from the use of trash fish to pelleted feed, from compressed pellets to extruded pellets, and from sinking feeds to floating feeds, to increase feed quality and reduce overfeeding. Training of farmers on the understanding

Figure 10. Fish pens in Dagupan, the Philippines

Source: G. Jacinto.

Figure 11. Fish cages in Waduk Jangari Dam, Indonesia

Source: Google Earth.

of eFCR (the ratio of the value of the feed fed to the value of the fish produced) would assist this process.

Poor farmer practice (overfeeding)

Farmers often believe that the more you feed the fish, the faster they will grow. Overfeeding of fish will allow the fish to grow at their maximum potential but at the same time, it will increase FCR, increase production costs, and increase nutrient release to the environment from uneaten food. Some feed manufacturers publish feeding tables that encourage higher feeding rates, which lead to increasing sales but poor FCR. Again, training is important for farmers to understand the biology of the fish to be able to provide the optimal amount of feed, the duration of the feeding, and the timing of the feeds. Various FAO TCP projects in Bangladesh, the Philippines, and elsewhere have addressed this problem, but it is important to disseminate the results and undertake training of farmers more widely.

Use of exotic species

Aquaculture is developing around non-native species (such as trout, Chinese carps, tilapia), which are potentially invasive with negative impacts on wildlife and wild fisheries. This is primarily due to those species being successfully cultured in other parts of the world and being easier to culture than native alternatives. It can take up to 20 years of research to develop a new local species for intensive culture and some local species are only widely known and have a strong market at the national level. The widespread culture of exotic species that are either easier to produce (such as tilapia and catfish) or more disease resistant (such as the white shrimp *Penaeus vannamei*) lead to countries producing fish or shrimp that are not known in the local market or competing with each other in the international markets.

MITIGATION OF AQUACULTURE POLLUTION

1. Approaches to mitigation

Three groups of interventions to mitigate aquaculture pollution are considered: public sector approaches; coordinated, public-private sector approaches; and private, farm-level approaches.

Public sector approaches, including support for the private sector

Sustainability, the principal goal of aquaculture governance, enables aquaculture to prosper over a long period. It entails economic viability, social license, environmental integrity, and technical feasibility. Economic viability requires that aquaculture operations be profitable over time and be competitive. Social license means the acceptance of aquaculture by neighboring communities and the wider society, and therefore determines where aquaculture development occurs. The principle of environmental integrity requires the mitigation of negative impacts so that farmers can continue production activities at the same site over a long period. There are a number of public sector approaches for planning, management, monitoring, and control of aquaculture development to minimize aquaculture impacts. In countries that already have strong aquaculture development or large potential for future development, there needs to be strong governance to plan, manage, and control the industry. This needs to be coordinated between the aquaculture department and the environmental department to ensure that environmental concerns are addressed appropriately.

- **Aquaculture policy.** Aquaculture policy is a broad vision for a sector, reflecting its directions, priorities, and development goals at various levels including provincial, national, regional, and international levels. Governments need to develop aquaculture sector policies, legislation, and regulations (separate from fisheries) to promote and manage sustainable aquaculture. There need to be scientific inputs for crafting policy and enacting aquaculture laws.

- **Aquaculture strategy.** Implementation of policy should be operationalized through a set of well-defined strategies and action plans. Aquaculture strategy is a roadmap for the implementation of a policy that contains specific objectives, targets, and instruments to address issues which might stimulate or impede the comparative advantage of the sector and obstruct its development.

- **Aquaculture action plan.** An aquaculture action plan is a time-bound, resourced plan of actions to achieve strategy objectives and implementation of strategy measures. For example, Scotland, Norway, and Ireland have strong governance for salmon culture and Vietnam has good governance for *Pangasius* catfish and shrimp but the majority of other Southeast Asian countries generally have weak and confused governance that needs to address the fast-growing industry. Examples of good governance are available but they need to be adapted to local conditions and sufficient funding and capacity need to be made available to develop and implement them.

Code of Conduct for Responsible Fisheries (CCRF)

The CCRF (the Code) was adopted by FAO in 1995 and remains key to achieving sustainable fisheries and aquaculture (FAO 1997). The Code provides the framework and its implementation is steered by four international plans of action, two strategies, and 28 technical guidelines, which have evolved to embrace the ecosystem approach. Most countries have fisheries policy and legislation that are consistent with the Code, while other countries have plans to align them with the Code. Globally, the priority for implementation is the establishment of responsible fisheries with due consideration of relevant biological, technical, economic, social, environmental, and commercial aspects (FAO 2011).

Two instruments are becoming important in support of the implementation of the Code: the EAA and zoning, siting, and area management through spatial planning. The two instruments are proving especially useful with regard to social license and the environmental integrity of aquaculture sustainability/governance.

The FAO regularly assesses the implementation of the code by governments. Seventy-one countries responded to the 2015 assessment, covering nearly 90 percent of the global aquaculture production. The results indicate an improving compliance with the CCRF aquaculture components of governance through aquaculture policy, planning, and regulation but that further efforts are required to improve implementation at the ground level by supporting and enhancing mechanisms and by improving the capacity of the states.

EAA planning, management, monitoring, and control

In an attempt to control or prevent inappropriate development of the aquaculture sector, several countries have adopted the EAA. The EAA is an approach to sector development and management that simultaneously considers physical, ecological, social, and economic systems, as well as a wide range of stakeholders, spheres of influence, and their interlinkages. Its application follows three main principles: (a) aquaculture development and management should take account of the full range of ecosystem functions and services and should not threaten their delivery to society; (b) aquaculture should improve human well-being and equity for all relevant stakeholders; and (c) aquaculture should be developed in the context of other sectors, policies, and goals. The FAO has elaborated and extended technical guidelines to facilitate comprehension and implementation of the EAA (FAO 2010). This holistic strategy aims to find management solutions to aquaculture development issues (including environmental concerns) and requires a management plan which is regularly monitored and evaluated against specific objectives with feedback to be developed to improve the management plan and ensure good control of the process. The EAA has been implemented in certain aquaculture regions but is not yet routinely used at the national level.

Zoning for aquaculture space allocation

Unplanned development of aquaculture in some areas of the world has also triggered environmental and social concerns, which, in turn, have led to a negative public perception of aquaculture. Spatial planning, including zoning and site selection, is increasingly being used to tackle these issues and at the same time ensure that aquaculture takes place in suitable areas. Where aquaculture is a new activity, zoning is used to identify and establish potential areas for its development; where it is well established, aquaculture zoning helps regulate its development to prevent overproduction within the allocated zone (FAO 2015).

Various other countries have also started using marine spatial management to achieve sustainable use of resources and biodiversity conservation in ocean and coastal areas. The enabling tool here has been marine spatial planning. This is a public process of analyzing and attaining spatial and temporal distribution of human activities in marine areas, with the aim of achieving ecological, economic, and social objectives as set forth by political processes. Zoning or allocation of space is a mechanism for more integrated planning of aquaculture development to avoid conflicts with fisheries (for example, sensitive wild fisheries, spawning, and nursery areas) and its better regulation.

Aquaculture zoning is now well practiced in countries such as Norway, Scotland, Australia, Turkey, and Malta but is not so well applied in Southeast Asia with the exception of zoning for disease control. In Southeast Asia, many countries such as the Philippines, Indonesia, and Thailand have decentralized governance from central to local level. This allows for more emphasis on local priorities but is influenced by local politics, is difficult to build capacity in every local government for good aquaculture planning and management, and is problematic for larger water bodies that are under the jurisdiction of a number of local governments.

Carrying capacity estimation

Each ecosystem has a different capacity to absorb and assimilate excess loading of organic compounds and nutrients from a farm or to absorb social changes, habitat modifications, and so on, that come with the farm. Therefore, aquaculture production facilities should adjust their production to the carrying capacity of the relevant waterbody and socioeconomic system. Carrying capacity estimation is undertaken as part of aquaculture zoning and or licensing of farms. Carrying capacity is typically undertaken using depositional models (particle tracking) which predict the particulate outputs from fish cage aquaculture and can be used in local-scale assessment of the effects of fish cages on the organic footprint impact on the sediment and sensitive demersal flora and flora. Particulate tracking models use the output from a spatially explicit hydrodynamic-dependent particle tracking models to predict (organic) flux from culture sites to the bottom. At the local scale, screening models may be used to look at aquaculture yields, local impacts of fish farming, and water quality. Government planning departments need to have the capacity to undertake carrying capacity estimations or have access to specialists who can make the calculations. In this way informed decisions can be made of the sustainable production in aquaculture areas.

Farm permitting, licenses, and registration

The aquaculture licensing system is a legally binding control procedure that allows the authorities to verify the viability of aquaculture at a proposed site and assess the potential environmental and social impacts of the operation. Licenses establish the physical dimensions of the site, acceptable operating conditions (especially production and pollution limits), and the period over which permission to operate is valid. In this way, the location, size, and number of farms can be controlled to prevent cumulative environmental impact. All permitting and leasing systems should include consideration of distances among existing and planned aquaculture sites and between aquaculture and other potentially conflicting uses. In countries where aquaculture planning and management have been devolved to the local government level, there are problems of capacity and understanding of good and sustainable licensing procedures and problems when one waterbody is under the jurisdiction of more than one local government area.

Strategic environmental assessment (SEA)

The SEA is defined as "a formalized, systematic, and comprehensive process for evaluating the environmental effects of a policy, plan or programme and its alternatives." The SEA is the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects associated with existing or new economic activities under a particular plan or program, within a particular sector, or within an identified physical area or region. The SEA is being used in various integrated coastal management initiatives so that strategic sustainable production plans can be set for particular waterbodies and licenses/rights can be issued accordingly. The SEA is a key tool in the delivery of sustainable development and the implementation of the associated ideas of the ecosystem approach and the precautionary principle. The SEA should be regularly used as a tool for identifying potential conflicts and impacts in new geographical areas of aquaculture development.

Environmental impact assessment (EIA)

The EIA has developed into a universal tool for planning. In many counties, it is a legal requirement to undertake an EIA before the start of large aquaculture ventures to identify and predict potential biological, physical, and social impacts of aquaculture, plan management, and mitigation measures within an EMP and consider reasonable alternatives (FAO 2009).

Initial environmental examination (IEE)

An IEE is required to identify whether or not a full EIA is required. Smaller projects that do not have the potential to cause significant environmental impacts may be required to undertake only an IEE. However, a full EIA study may be required after an evaluation has found that an IEE is not sufficient to address the environmental impacts of the project. The IEE is a scaled-down EIA with a mini-EIA report.

Environmental management plan (EMP)

An EMP is normally a requirement of the EIA. An EMP is a site- or project-specific plan developed to ensure that appropriate environmental management practices are followed during the construction and/ or operation of a project to minimize environmental impacts.

Environmental monitoring audit

An environmental impact audit undertakes evaluations intended to identify environmental compliance and management system implementation gaps along with related corrective actions. This way, they ensure that environmental impacts are within the accepted limits.

Public-private approaches

In many Southeast Asian countries, there is insufficient capacity within the government departments to mitigate environmental impacts and reduce pollution from aquaculture. The private sector is becoming more fully engaged, shouldering more responsibility for achieving sustainability, and, together with the public sector, has developed certain measures and approaches.

Area management - fallowing and environmental monitoring of farm clusters

The management of aquaculture farms in an area is a good way for the private and public sectors to work together to coordinate and cooperate to balance environmental, socioeconomic, and governance objectives. Such designated aquaculture management areas can be aquaculture parks, clusters, or any area where farms share a common relevant waterbody or source and may benefit from a common management system. Typically, clusters of farms in a defined aquaculture area form a management committee to foster cooperation and coordination between the members for biosecurity, fish health, and environmental management. Environmental management of these areas can include fallowing of sites to allow sediments and water quality to improve at the end of a production cycle.

Aquaculture and mariculture parks

The development of aquaculture or mariculture parks provide zones for clusters of small-scale farmers that can be managed and monitored sustainably and responsibly. By ensuring that production activities are conducted in a sustainable manner, such a strategy has also resulted in increased socioeconomic benefits to communities. The Bureau of Aquatic and Fisheries Resources in the Philippines has developed mariculture parks as a strategy for controlled aquaculture development (see Philippine case study below).

Integrated multitrophic aquaculture (IMTA)

The IMTA is an aquaculture production system where the output (nutrient waste) of one subsystem is utilized by another sequentially linked subsystem to extract nutrients, resulting in a greater efficiency of the overall system. Subsystems can either comprise aquatic species, fisheries, agriculture, livestock, or other human activities. The aim of integrated production is to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction), and social acceptability (BMPs). Effective integration of combinations of fed aquaculture and such 'extractive' aquaculture practices can result in a net increase in productivity and can mitigate against nutrient build-up in the environment. Mixed culture of fish, mollusks, and seaweeds practiced in the coastal bays of China is a good example. If densely located, even extractive aquaculture systems can cause negative impacts on the environment, especially on sediments, as a result of fecal and pseudofecal accumulation.

Integrated irrigated aquaculture (IIA)

The IIA is a concept which integrates aquaculture and agriculture and has been developed to maximize water use efficiency, for example, by developing and enhancing fisheries in irrigation small water bodies, by reusing irrigation water leaving irrigation plots for feeding fish ponds, by stocking fish in irrigation canals, by building ponds in adjacent waterlogged areas unsuitable for agriculture, by using crop by-products as nutrient inputs for farmed fish, and by fertilizing irrigated vegetable gardens and orchards with pond sludge deposits and irrigating rice fields, vegetable plots, and orchards with fertilized pond water such as *Pangasius* pond effluent in Vietnam.

Algal ponds

Algal ponds. Algae culture (plant culture in general) is a type of extractive aquaculture that assimilates aquaculture effluents mainly composed of solids (carbon, nitrogen, and phosphorus) and soluble wastes (carbon dioxide, ammonia, orthophosphate, and trace elements) into biomass. In integrated aquaculture, algal biofilters reduce the environmental impact of fish culture. The algae species selected as the biofilter can be chosen to provide additional benefits, including sale for human consumption, or for phycocolloid, feed supplement, agrichemical, nutraceutical, and pharmaceutical-compound production. High-rate algal ponds may constitute a second loop of water treatment of flow-through or recirculating aquaculture systems.

Constructed wetlands

Natural wetland systems can have a positive effect on the quality of water that passes through them. Particulate matter suspended in the inflow water, along with dissolved organic nutrients, coliform bacteria, and even industrial and agricultural chemical pollutants, can be significantly reduced. Constructed wetlands are very effective at removing suspended solids. Most of the removal occurs within the first few meters of the first cell, where the compacted gravel and soil provide a physical filter. Constructed wetlands are considered a viable and cost-effective method to treat waste water. The addition or integration of a constructed wetland into an aquaculture production process represents an environmental enhancement.

Regular environmental monitoring

Monitoring is often designed at the end of the EIA and is part of the EIA statement. The monitoring protocol proposes what type of indicators should be used to monitor the impact of the farm at various points in time. It usually focuses on environmental parameters. The environmental monitoring results support decision makers as well as the producer himself with an estimation of the size of the impacts (extent and severity) and ways to improve management and regulate the activity.

Better management Practices (BMPs)

BMPs are a set of guidelines that promote improved farming practices to increase production and profitability through responsible and sustainable aquaculture. There is a significant level of variation in BMPs for different commodities, culture systems, and locations. In India, BMPs implemented by farmer clusters have resulted in improved yields, fewer disease occurrences, and higher profitability, as well as other private and public benefits.

In the Philippines, each mariculture park has an operations manual containing production guidelines and management measures. Following the principles of Good Aquaculture Practices, it serves as the guideline for all activities within the parks. The guideline covers zone and farm location, layout and design, biosecurity sanitation and hygiene, waste storage and removal, good farm management measures including feeds and feeding, farm effluent treatment, worker health and safety, disease diagnosis, treatment and chemical use, harvesting, postharvest, traceability, and food safety.

Improved feed formulation and feeding strategy

Through the use of good quality and stable feeds and by practicing good feed management, it is possible to significantly reduce the impact of wastes in such environments. Innovations in automated feeding technology and feed form/composition have significantly reduced feed inputs and effluent loads per unit of production, while maintaining productivity. In salmon farming over the past decade, feed conversion ratio has been steadily decreasing, from 1.5 to nearly 1.0. Such reduction implies the discharge of less organic matter and nutrients into the environment. However, other types of aquaculture (milkfish and grouper in Asia and sea bream and sea bass in the Mediterranean Sea) still need to improve their feed conversion ratios, and strong regional efforts are being made to address this task.

Environmental certification

There are a number of certification schemes such as the Aquaculture Stewardship Council and Global Aquaculture Alliance that aim to promote environmental sustainability and social responsibility using market mechanisms at the farm scale. In this way, the environmentally certified farms credibly demonstrate that their production practices are non-polluting, non-disease transmitting, and/or non-ecologically threatening. Certification primarily is aimed at farmers who are exporting their products rather than supplying local markets. Therefore, there is a need to create local and national incentives for certification and labelling; for example, this is followed in China, to make local consumers more aware so they can choose environmentally friendly products.

Some countries such as Vietnam have introduced state-mediated certification procedures to ensure that aquaculture products are safe to consume and farmed in accordance with certain environmental standards. The Global Aquaculture Alliance is also developing certification schemes for clusters of small-scale farmers.

Farm-level approaches

Intensification of aquaculture practices has resulted in farms generating greater volumes of suspended solids. As fish farm units produce more fish, separation of solids from the water flow before discharge from the site becomes more important. This is particularly true where a number of fish farms are located close together on one river or, in the case of marine farms, where farms discharge close to one another into the sea. The need for treatment is greater where there is a low rate of dilution of the effluent by the residual river flow or marine tides. There are two methods for reducing suspended solids in fish farm effluent: sedimentation and mechanical filtration.

Sedimentation

Suspended solids can be removed from effluents by gravitational sedimentation. However, the specific gravity of fish feces is close to that of water and therefore the rate of their sedimentation is low. Sedimentation of suspended solids is made more difficult by degradation of the feed or feces 'pellet' as it travels from the fish through the fish-holding area to the sedimentation basin. Very small particles become 'non-settling solids'. This degradation of feces into smaller particles, when combined with time exposure in the water, leads to a portion of the nutrients contained in the solids becoming dissolved. Fish farm design should therefore aim to trap and remove suspended solids as early as possible after being deposited by the fish, to reduce this degradation process. This is typically undertaken by effluent passing through sedimentation ponds before being discharged into the water body.

Table 2. Key polluting factors and potential solutions

Polluting Factor	Public Sector	Private Sector
Poor site selection	• Creating aquaculture zones that are suitable for aquaculture • Licensing system that evaluates site suitability based on site selection criteria • Enforcing EIA or IEE before start-up	• Training in site suitability criteria
Over production at farm level	• License linked to maximum allowable production • Codes of Conduct for farm operation • Enforcing environmental monitoring and reporting	• BMPs • Codes of best practice from producer organizations • Installation of effluent setting ponds
Over production at water body scale	• SEA • Carrying capacity estimation • Limits on number of licenses issued • Regular environmental monitoring at the waterbody scale	• Aquaculture area management by the farmers themselves
Poor feed quality	• Aquaculture feed standards	• Training on eFCR
Poor feeding strategy	• Codes of Conduct for farm operation • Scientifically developed feeding tables	• Training on feeding strategy and prevention of over feeding
Use of exotic species and exotic strains or genetically improved strains	• Risk assessment for introductions • Research on aquaculture of local species	• Better systems for the prevention of escapees (for example, stronger nets, flood protection)
Release of chemicals, antibiotics, and so on	• Clear regulations, monitoring, and local assessments • Biosecurity frameworks in place	• Farmers organizations and aquaculture management areas addressing health issues and implementing biosecurity measures

Mechanical filtration

Mechanical filters remove solids from water using physical barriers through which the solid particles cannot pass. This is usually achieved using a medium such as sand or with mesh. Mechanical filters will remove both settling solids and those that will not settle due to their small particle size or low density.

Table 2 summarizes the key factors influencing higher pollutant outputs resulting in impacts to the environment and provides some mitigating solutions and indicates the possible roles of the public sector in supporting, initiating, funding, and regulating and the role of the private sector in implementing solutions at the farm level.

2. Examples of mitigation approaches within and outside the region

Mitigation efforts in China, Vietnam, and the Philippines

A number of nutrient pollution mitigation measures have been developed and tested in the three focus countries and could be replicated further.

China

Development of aquaculture and integrated cultures has a long history in China, such as the mutual profitable relationship between grass carp and rice and the optimized ratio for stocking silver carp and grass carp. Open-water mariculture started much later than freshwater aquaculture in China. Large-scale integrated mariculture started in 1975 with simultaneous culture of mussel and kelp along a large part of the coastline. In the beginning of the 1980s, polyculture of kelp, scallops, and sea cucumber gave good results. Currently, the integrated mariculture of kelp and scallops, abalone, and sea cucumber are widely applied in open waters. Integrated mariculture has become common practice in China, especially in pond farming. The integrated mariculture of shrimp and mollusks and/or crabs and/or macro-algae are popular because they help in the prevention of outbreaks of white spot disease (White Spot Syndrome Virus). Additionally, temporal integration, like rotary stocking and harvesting, is popular. An example of this is the integrated shrimp and crab culture, where shrimp are harvested first and crabs several weeks later to keep constant biomass in the pond, and in rotary stocking and harvesting of five different species.

Vietnam

In Vietnam, there has been rapid development of highly intensive *Pangasius* pond culture. Catfish are stocked in deep ponds and fed a high level of feeds. This results in large quantities of sludge settling on the pond floor and pond effluents with high nutrient concentration. Lately, there has been an increasing use of nutrient-rich pond effluent water being used to irrigate rice fields and sludge used to fertilize orchards. This allows the nutrients to be reclaimed before returning back into the river or water table.

Phan et al. (2009) estimated that approximately 35 percent of catfish farms in the Mekong Delta discharge water directly onto rice fields or gardens. However, more detailed studies on the nutrient dynamics within the Mekong Delta, incorporating catfish farming and its interactions with other primary production sectors (especially rice farming), are required.

The World Bank-funded Coastal Resources for Sustainable Development for Vietnam Project was initiated to improve the sustainable management of coastal fisheries in the project provinces. One of the initiatives is the demonstration of the construction of individual farm settling ponds for shrimp farms. Shrimp pond effluent is passed through a settling pond (20 percent of the total farm pond surface area) to collect nutrients before discharge into the joint effluent canal. These settling ponds have been found to be a cost-effective tool for treating effluent water. It provides for settling of organic (nutrient and bacterial) loading. The design of a settling pond influences effectiveness and must be sized correctly in terms of volume and residence time.

The Philippines

The Norad-funded project 'Environmental Monitoring and Modelling of Aquaculture in Risk Areas in the Philippines' (http://aquaculture.asia/pages/5.html; Palerud et al. 2009) and the European Union-funded project 'Mitigating Impact of Aquaculture in the Philippines' (http://aquaculture.asia/pages/10.html) in 2008 pointed out that the impact of aquaculture to the environment is caused by the following factors: feed quality, water stability of feed, and digestibility. Overfeeding results in excess nutrients entering the water column and being deposited at the sea/lake bottom. Accumulation of these nutrients degrades the water quality and decreases the oxygen level in the sediment below the cages, making the aquaculture area prone to fish kill. Reducing the risk of environmental degradation requires minimizing waste from uneaten feeds and improving feed quality. The FAO TCP project (TCP/PHI/3404) focused primarily on increasing the feeding efficiency by reducing feed conversion ratios (FCRs) for milkfish and Nile tilapia by addressing the factors, including the suitability of the formulation in terms of supplying the nutritional requirements of the cultured species, improving the digestibility of the feed ingredients, the stability of the feed in the water, and at the same time developing improved feeding strategy to reduce feed wastage.

International examples of direct relevance to the three countries

There are examples from other countries of good practice that minimized aquaculture pollution that could be applied in the three target countries. These include better management at the water body scale by the public and private sectors in Scotland and better planning of shrimp pond development to integrate shrimp culture with the environment.

Scotland - Area management agreements

Spatial management has become increasingly important, particularly for fish health and environmental protection. Government and industry collaborate in the operation of area management systems. Disease Management Areas are used by the government to control notifiable disease, particularly ISA. Current government policy is against new sites that would join Disease Management Areas. Farm Management Areas are industry-defined areas in which farms collaborate on management issues, including sea lice treatment. Sea lochs (small fjords) are assessed for carrying capacity, and maximum biomass content is limited to prevent environmental impacts arising from cumulative discharges. At a larger scale, large areas are reserved with no aquaculture, including the north and east coasts of Scotland where significant wild salmonid populations are found. New farms are given development consent under town and country planning by local authorities, considering views of primary stakeholders and in accordance with established policies in Scotland's National Marine Plan and any local plan. Standards are enforced by inspectors working for the Fish Health Inspectorate and the Scottish Environment Protection Agency and through industry codes of practice (COPs). This provides a good zonal framework for planning and management of aquaculture particularly for fish health and environmental protection that allows strong governmental control but also management at the local scale.

Thailand - Mangrove fringe for brackish water ponds (Tookwinas 2004)

In Kung Krabaen Bay, located in Chantaburi Province east of Thailand, King Bhumibol Adulyadej initiated the establishment of the Royal Development Study Centre in 1981 to develop a harmonized system among aquaculture, fisheries, and mangroves in the coastal area of the province. The main purpose was to demonstrate and promote sustainable shrimp culture practices. The mangrove forests assimilate nutrients from the shrimp ponds as well as provide good spawning and nursing ground for many fish and shellfish. The bay is also a source of livelihood for fishermen and serves as the site for the province's shrimp culture zone. Black tiger shrimp culture in the bay area increased the income and improved the standard of living of the shrimp farmers.

There is now a policy by BFAR in the Philippines to plant mangroves in abandoned ponds, particularly in the coastal fringe, to redevelop a coastal mangrove belt.

Reduction in antibiotic use in Norway

Shortly after the development of intensive salmon farming in Norway, severe problems with bacterial diseases (vibriosis, cold water vibriosis, furunculosis, and so on) emerged, but the diseases were treated unsuccessfully with antibiotics. The problem continued to increase and by 1987, antibiotic use reached a peak with close to 50 tons being administered during the year. A major review of the industry was then undertaken, including the implementation of better environmental practices and the development and widespread use of fish vaccines. By 1994, fish farmers across Norway had made the switch from antibiotics to vaccination. The vaccine is injected into the abdomen of salmon during their fresh-water phase using an automated process. This change was very successful and antibiotic use in salmon has remained at less than 1,000 kg a year since 1996. This achievement was the result of a strong collaboration between the government, farmers, industry, and the fish farming association.

A similar trend is seen in the production of salmon in Canada, both in its west coast farming operations and those in its maritime provinces. Vaccines are not yet used widely in Southeast Asia and more funding is required for the development of cost-effective vaccines for tropical diseases to help improve farmer productivity and profitability and reduce the amount of medication used.

Case studies and international examples illustrating best practices

The three case studies below illustrate some models and measures that other countries have developed to plan and manage aquaculture sustainably.

Case study 1. Development of mariculture parks in the Philippines

The Government of the Philippines, through the Bureau of Fisheries and Aquatic Resources, is promoting the development of mariculture zones and parks as a way of responsible and sustainable development of coastal cage aquaculture to provide livelihood to local communities and contribute to food security. This is in response to haphazard aquaculture development that has often led to boom-bust cycles. At present, there are over 60 mariculture parks in operation throughout the Philippines. The concept of the mariculture park is patterned upon the development of an industrial estate in a designated zone within municipal waters, wherein aquaculture plots are leased to small- to medium-sized aquaculture farms and infrastructure (mooring systems, navigation lanes, and docking areas), utilities (support facilities), and technical services are provided by the Government. The development process for setting up and operating a mariculture park follows a well-defined set of steps. The main features of the mariculture park development include:

- Shared infrastructure - Multiproduct onshore warehouse, cold storage, and ice plants facility service, as well as ferry boats and communal mooring system;
- Shared services - Availability of seeds and feeds supplier, cage fabricator, and manpower services;
- Shared Security - Internal and external security; and
- Sustainability - The selection of suitable zones for small- and medium-scale aquaculture development. Production is controlled to within the carrying capacity of the zone. The

environmental impact of the clustered farmers within the zone is regularly monitored.

The implementation of the concept requires strong Government commitment in terms of technical and some financial support at the starting phase. However, once operational, it contributes to controlled and managed development on the side of the Government and facilitated aquaculture livelihood development for small-scale farmers (White and Lopez 2017 in Aguilar-Manjarrez, Soto, and Brummett 2017). This concept is being replicated in other countries such as Sri Lanka and Uganda.

Case study 2. Zoning and management of aquaculture in Chile

The Chilean salmon farming industry has shown an impressive growth. In 25 years, the country has developed from a very low level of aquaculture production to become the leading farmed trout producer and second in terms of farmed salmon producer after Norway. In general, regulations lagged industry growth, generating several gaps that did not help prevent environmental/sanitary problems. In 2007, the ISA salmon disease crisis caused enormous impact on the industry with important socioeconomic consequences. This crisis was the trigger for the government to develop and implement profound change in regulations to manage and control sustainable development using the spatial management of farms into varying sizes of zones. Farms are grouped into neighborhoods and groups of neighborhoods into macro zones. Currently, an integrated spatial management system is in place which, in spite of its weaknesses, has helped coordinate efforts to control diseases, improve efficacy of measures in front of a sanitary risk, and create better conditions for environmental/sanitary recovery of the macro zone. Further improvements have to be made to move closer to an ecosystem approach to aquaculture, principally emphasizing carrying capacity studies and tools, interaction with communities and other sectors and also increasing participation, and developing incentives regime (Alvial 2017 in Aguilar-Manjarrez, Soto, and Brummett 2017).

Even with these new measures, it was not sufficient to prevent a recent algal bloom in the aquaculture area that has had a major impact on production in 2016. Nutrients from aquaculture may have contributed to the development of the algal bloom.

Case study 3. Moving cage culture from inshore to offshore in Turkey

Turkish marine aquaculture has seen rapid growth along the Aegean coast since 2000. However, there was an overdevelopment of small inshore cage farms that contributed to poor water quality and algal blooms and conflict with other coastal zone stakeholders.

Figure 12. An example of coastal shrimp ponds in Krabaen, Thailand

Source: Siri Tookwinas.

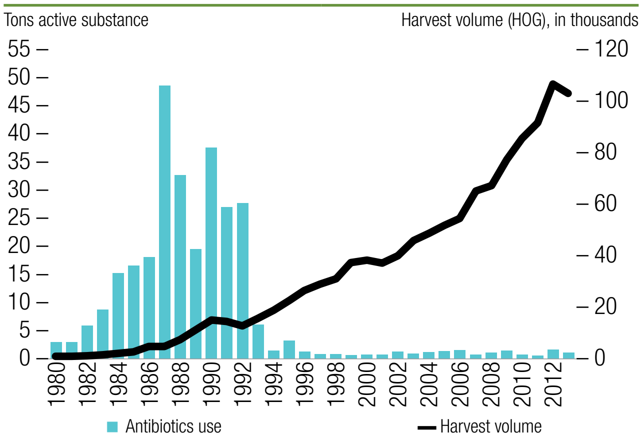
Note: The ‘mangrove belt’ protects the fish ponds against typhoons and storm surges, as well as serve as a nursery grounds for different species of marine organisms.

Figure 13. An example of coastal fringe ponds in the Philippines

Source: BFAR, Philippines.

Note: Mangrove forests were cut down to construct fish ponds and no mangrove left to protect the coast.

Figure 14. Antibiotic use in Norwegian salmon production



Source: Based on data from the Norwegian Directorate of Fisheries, provided by Frank Asche.

This spurred the Ministry of Environment and Urbanization in 2008 to issue new regulations to move inshore farms to offshore locations (1 km from the coastline) and set up new mariculture zones. Site selection and zoning addressed basic issues and were carried out through a participatory process among stakeholders, scientists, and the Central government. This has subsequently proved to be a weak point in the whole process. Zoning EIA reports were produced for the zones and regular environmental monitoring was done by government officers.

Aquaculture zoning, spatial planning, aquaculture management, and risk mapping are among the most important issues for the success of aquaculture. They need to be carried out in accordance with sustainability and best practice guidelines. Turkey has recently focused on such issues and is trying to set guidelines which would enable true sustainability to take place by incorporating the estimation of carrying capacity of a new aquaculture potential area into the EIA process.

The measures that the Government of Turkey took were strong and forced many small-scale producers to leave the industry as they were not able to make the necessary financial investment, but it ensured that aquaculture development takes place in suitable designated aquaculture zones and laid the foundations for a long-term future sustainable growth of the industry. Countries such as Greece have not followed this lead and so continue to suffer from environmental impact and conflict with other users of the aquatic and coastal resource (Yücel-Gier 2017 in Aguilar-Manjarrez, Soto, and Brummett 2017).

Potential solutions with potential applicability in the contexts of the three study countries or the region more broadly

Good aquaculture planning practices

Good planning practices include zoning, carrying capacity estimation, EIAs, and licensing with production caps. There are a number of tools (such as geographic information system, carrying capacity models, environmental impact models) that can assist decision making for identification of aquaculture zones, farm 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 helps to prevent local impact. Modelling clusters of farms helps prevent more widespread impact in water bodies and 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.

Driven mainly by environmental and disease control concerns, good planning practices are currently undertaken by the governments of countries such as Norway, Scotland, and Turkey, but they require strong government capacity to implement them. These tools could be easily adapted for other countries, but capacity needs to be built and resources allocated for this to happen.

Good aquaculture management practices

Good management practices include regular environmental monitoring of farm sites and clusters of farms in zones, coordinated disease prevention (vaccination) and treatment, and management of biosecurity. In some cases, these practices are mandatory, such as for environmental monitoring, but in other cases are undertaken by the farmers individually or collectively. The problem is how to motivate farmers to have better management skills. If there are strong financial rewards, such as better biosecurity leading to improved survival and productivity, farmers will be motivated. However, deteriorating water quality may not be linked in the mind of the farmer to poor production practices and so they are not motivated to make improvements individually. The increasing use of good practice certification is motivating farmers to improve as they can increase market demand and/or price for their products.

Integrated and integrated multi-trophic aquaculture (IMTA)

Integrated aquaculture includes aquaculture-agriculture (for example, rice-fish/shrimp farming) and aquaculture-silviculture. The IMTA is a practice in which by-products (wastes) from one species are recycled to become inputs (fertilizers, food, and energy) for another. Fed aquaculture species (for example, finfish/shrimps) are combined in appropriate proportions with organic extractive aquaculture species (for example, suspension/deposit feeders, herbivorous fish) and inorganic extractive aquaculture species (for example, seaweeds). The IMTA is often difficult to be implemented by individual farms as it requires expertise in very different culture practices (fish/bivalves/seaweed), different production equipment, and different markets. In Asia, however, these secondary production practices (bivalves and seaweed) can be undertaken by separate farmers who are benefiting from the nutrient output from the fed aquaculture. This requires appropriate planning of landscape integration. In addition, the investment requirement to set up these secondary production systems are much less as there are no feed costs.

Better management practices (BMP) and codes of practice (COP)

BMPs are a practical and economically feasible way to reduce adverse environmental impacts of aquaculture at the farm level and also at larger scale, and so reduce conflicts with fisheries. Implementing BMPs requires action from both the 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, and so on. BMPs are generally developed as the first step toward the certification of individual farms and clusters of farms. COPs are generally developed by aquaculture producer organizations to ensure that their members conform to good standards of production.

CONCLUSIONS AND RECOMMENDATIONS

Aquaculture development in some Asian countries is characterized by weak and sometimes poor governance. Poor governance results in poor planning, poor management, and in some cases, boom-bust cycles and fish kills. Many environmental impacts of aquaculture result from the sum of individual farms but they are rarely addressed at this more 'ecosystemic level'. While EIAs, licensing, and certification systems are required for individual intensive/large-scale types of farms, there are no mitigation approaches or management measures covering the overall impact of small farms collectively. Specific areas for focus for capacity building and improvement include zoning and carrying capacity assessment, followed by pollution management and EIA and mitigation.

Public sector interventions

Effective governance through sound policies, strategies, and action plans incorporating the principles of an EAA and good linkages between government policies and sustainable management of aquaculture. Institutions were strengthened, capacity improved, and more effective mechanisms of governance were developed, including rules and regulations, planning and management, together with voluntary COPs, and responsible self-management. However, the capacities for governance—central and local governance and voluntary management—require further strengthening across the Southeast Asian region.

- **Legislation and regulations.** For sustainable and responsible aquaculture development, there should be facilitating and controlling legislation and regulations. With 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 lack of integrated planning, communication, understanding of the interactions, and insufficient consideration of the different ecological and management scales. In addition, implementation is poor or lacking, or the policies, legislation, and regulations are not understood by farmers. Responsible government units should translate relevant policies into understandable statements. In general, there is a lack of use of the ecosystem approach to fish production in general.

- **Implement and reinforce Codes of Conduct for Responsible Fisheries.** Governments and other stakeholders should work to effectively implement the provisions of the CCRF and to apply, as appropriate, the elements in the Guidelines for Fisheries and Aquaculture. The huge aquaculture development of recent decades has been primarily driven by market forces and not always aligned with development priorities related to conservation, food security, and poverty alleviation. Nevertheless, there are important efforts to reduce key negative environmental impacts through compliance with standards at the farm level, as, for example, through various certification schemes, supported or guided by globally agreed schemes such as the FAO aquaculture certification guidelines. However, greater efforts are needed for implementation, especially focusing on small-scale producers in developing regions.

- **EAA.** The EAA should be applied when planning aquaculture development to explicitly address issues such as the availability of water and space or other external factors such as water pollution and consumer perceptions. The EAA is particularly needed to account for the sector's environmental services and minimize its environmental impacts. It can also be useful in planning the spatial distribution of aquaculture, make carrying capacity considerations, and consider possible impacts on communities' well-being. Development of a spatial plan/design for aquaculture growth and expansion should also be part of the initial planning at the farm/watershed level, based on the ecosystem carrying capacity. Implementation of the EAA can be best achieved in designated aquaculture management areas. These can be aquaculture parks, clusters, or any area where farms share a common relevant waterbody or source and may benefit from a common management system. They must have a management system that strives to balance environmental, socioeconomic, and governance objectives, and they should consider the sharing of benefits with local communities and their involvement (as appropriate) in the development of a management plan, its implementation, and monitoring.

- **Coastal zone planning and management.** As aquaculture is relatively new and growing rapidly, it can result in conflicts with other more mature sectors such as fisheries, agriculture, irrigation, and industry, as well as increasing urbanization. Principle 3 of the EAA is essentially a call for more integrated planning and management systems, as has been advocated for many years through integrated coastal zone management and integrated watershed management. This can be achieved using integrated natural resource management such as integrated coastal zone management and integrated watershed management. Good coastal planning and management will reduce the risk of overproduction leading to localized water quality problems and reduce boom-bust aquaculture cycles.

- **Siting and zoning.** Many of the space- and habitat-related impacts of aquaculture development on traditional fisheries can be reduced or eliminated altogether 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 (for example, sensitive wild fisheries, spawning, and nursery areas), as well as its better regulation. It may also be used as a basis for coordinated management of aquaculture area using area management plans.

- **Carrying capacity estimation.** Before aquaculture is established in a certain area, the carrying capacity should be estimated using appropriate models, together with representative observational data from the area and any water quality standards or criteria as well as any of the Environmental Quality Standards in force. The carrying capacity for a zone or site can be estimated using such models together with field data and the water quality and environmental quality standards in force. The assessment of ecological carrying capacity uses the assimilative capacity approach which estimates the ability of the ecosystem to deal with inputs of waste wherever they arise to maintain a healthy environment.

Public-private partnerships and other approaches—cluster management, and so on

Appropriate mechanisms for good practice, quality control, and monitoring established for all upstream inputs, production, and downstream outputs along the aquaculture value chain including efficient resource use and improved productivity, value added, and profitability. Training for farmers, extension technicians, and farm managers in sustainable production technologies and methodologies need strengthening.

- **Codes of best practice and BMPs.** BMPs are a practical and economically feasible method to reduce adverse environmental impacts of aquaculture at the farm level. The BMP 'solutions' require action from producer organizations developing Codes of Best Practice and from the farmers through BMPs.

- **Aquaculture certification.** The aquaculture sector would benefit from international standards and certification systems to promote environmentally acceptable products.

- **Optimizing feeds and feeding strategy.** Farms should try to improve their feeding efficiency and optimize feed conversion factors to increase profits and to decrease nutrient and organic matter loses. This can be achieved by using better formulated and quality feeds (higher digestibility, better binders) and improved feeding strategy to reduce overfeeding.

- **Integrated aquaculture.** Integrated aquaculture can be considered a mitigation approach against the excess nutrients/organic matter generated by intensive aquaculture activities and may be relevant in some circumstances. In this context, IMTA has emerged recently, in which multi-trophic refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system.

Table 3 tries to summarize where focus countries are weak or strong in any of these measures and what level of implementation and where potential lies.

Table 3. **Summarizing pollution mitigation measures for focus countries**

Measures	China	Vietnam	Philippines
Appropriate legislation and regulations	Good specific and proactive regulations and policy with special emphasis on aquaculture.- -In addition, local laws and regulations, which proceed from specific conditions in their geographical areas	Good specific aquaculture regulations and reasonably implemented	Numerous specific regulations for aquaculture but poorly implemented
Implementing Codes of Conduct for Responsible Fisheries	Incorporated into policy	Incorporated into policy	Incorporated well into policy, strategy, regulations, and action plans
Implementing ecosystem approach to aquaculture	Not yet implemented	Some pilot projects for specific issues but not yet widely implemented	Implemented in some pilot projects but not yet widely implemented
Implementing coastal zone planning and management	Reasonable planning and management	Adequate planning and management of inland water but poorer in coastal and marine waters	Implemented al the local government level but poor at the water body scale when there are more than one local government unit involved
Good aquaculture Siting and zoning	Zoning in some areas only	Much of aquaculture already in traditional areas	Undertaken for mariculture parks and some lakes only
Carrying capacity estimation	Undertaken for specific areas only	Not routinely undertaken	Undertaken for mariculture parks and some lakes only
Codes of best practice and BMPs	Numerous guidelines have been issued, at both the national and the provincial level for the operation of hatcheries and the use of antibiotics and chemicals but not widely implemented	Strong COPs and specific BMPs for *Pangasius* catfish production	Code of Practice published but not widely implemented. BMPs for mariculture parks.
Aquaculture certification	Some larger farms certified.	Some larger farms certified	Not many farms certified.
Optimizing feeds and feeding strategy	—	Still use of farm made feeds for *Pangasius* catfish farming and use of trash fish for marine farms	Many feed producers. There are feed quality standards but there is much variation in feed quality.-- Generally poor feeding strategy but increasing use of floating feeds
Integrated aquaculture	Widely used and practiced	Production primarily monoculture	Not yet widely practiced

REFERENCES

Aguilar-Manjarrez, J., D. Soto, and R. Brummett. 2017. "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture: A Handbook." Report ACS113536. FAO and World Bank, Rome. http://www.fao.org/3/a-i6834e.pdf.

Alvial, A. 2017. "Chile Case: The Spatial Planning of Marine Cage Farming (Salmon)." In "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture: A Handbook," edited by J. Aguilar-Manjarrez, D. Soto, and R. Brummett. Report ACS113536. FAO and World Bank, Rome. http://www.fao.org/3/a-i6834e.pdf.

Asche, F. 2008. "Farming the sea." *Marine Resource Economics*, 527-547. http://www.nmfs.noaa.gov/aquaculture/docs/aquaculture_docs/marine_perspectives_farming_the_sea.pdf

Burridge, L., J. S. Weis, F. Cabello, J. Pizarro, and K. Bostick. 2010. "Chemical Use in Salmon Aquaculture: A Review of Current Practices and Possible Environmental Effects." *Aquaculture* 306: 7–23.

Cui, Y., B. J. Chen, J. F. Chen. (2005): Evaluation on self-pollution of marine aquaculture in Bohai Sea and Yellow Sea. Chinese journal of applied ecology 16, 180–185 (in Chinese with English abstract)

De Silva, S. S., B. A. Ingram, T. P. Nguyen, T. T. Bui, G. J. Gooley, and G. M. Turchini. 2010. "Estimation of Nitrogen and Phosphorus in Effluent from the Striped Catfish Farming Sector in the Mekong Delta, Vietnam." *Ambio* 39: 504–514.

FAO (Food and Agriculture Organization). 1997. "Aquaculture Development." FAO Technical Guidelines for Responsible Fisheries. No. 5, FAO, Rome, 40 pp. www.fao.org/docrep/003/W4493E/w4493e01.htm#abs.

———. 2009. "Environmental Impact Assessment and Monitoring in Aquaculture." FAO Fisheries and Aquaculture Technical Paper. No. 527, FAO, Rome, 57 pp. Includes a CD-ROM containing the full document (648 pages). www.fao.org/docrep/012/i0970e/i0970e00.htm.

———. 2010. "Aquaculture Development. 4. Ecosystem Approach to Aquaculture." FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 4, FAO, Rome, 53 pp. www.fao.org/docrep/013/i1750e/i1750e00.htm.

———. 2011. *Code of Conduct for Responsible Fisheries*. Rome: Food and Agriculture Organization of the United Nations. 91 p.

———. 2014. *The State of World Fisheries and Aquaculture 2014 (SOFIA)* 4. Rome: FAO. 223 pp. http://www.fao.org/3/a-i3720e.pdf.

———. 2015. "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture" Policy Brief, FAO, Rome. 4 p. http://www.fao.org/3/a-i5004e.pdf.

FAO/World Bank. In Press. Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture

Holby, O., and P. O. J. Hall. 1991. "Chemical Fluxes and Mass Balances in a Marine Fish Cage Farm. II. Phosphorus." *Marine Ecology Progress Series* 70: 263–272.

Kapetsky, J. M., and J. Aguilar-Manjarrez. 2013. "From Estimating Global Potential for Aquaculture to Selecting Farm Sites: Perspectives on Spatial Approaches and Trends." In *Site Selection and Carrying Capacities for Inland and Coastal Aquaculture. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland*, edited by L.G. Ross, T.C. Telfer, L. Falconer, D. Soto, and J. Aguilar-Manjarrez, 129–146. FAO Fisheries and Aquaculture Proceedings No. 21. FAO, Rome, 282 pp. www.fao.org/docrep/017/i3099e/i3099e00.htm.

Karakassis, I., P. Pitta, and M. D. Krom. 2005. "Contribution of Fish Farming to the Nutrient Loading of the Mediterranean." *Sci Mar* 69: 313–321.

Murray, A., and M. Gubbins. 2017. "Aquaculture Zoning, Site Selection and Area Management in Scottish Marine Finfish Production." In "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture: A Handbook," edited by J. Aguilar-Manjarrez, D. Soto, and R. Brummett. Report ACS113536. FAO and World Bank, Rome. http://www.fao.org/3/a-i6834e.pdf.

Palerud, R., G. Christiansen, T. Legovic, P. White, and R. Regpala. 2009. *Environmental and Production Survey Methodology to Estimate Severity and Extent of Aquaculture Impact in Three Areas of the Philippines*. ftp://ftp.fao.org/fi/Cdrom/T583/root/21.pdf.

Phan, L. T., T. M. Bui, T. T. T. Nguyen, G. J. Gooley, B. A. Ingram, H. V. Nguyen, P. T. Nguyen, and S. S. Silva. 2009. "Current Status of Farming Practices of Striped Catfish, *Pangasianodon hypophthalmus* in the Mekong Delta, Vietnam." *Aquaculture* 296: 227–236. doi:10.1016/j.aquaculture.2009.08.017.

Ross, L. G., T. C. Telfer, L. Falconer, D. Soto, and J. Aguilar-Manjarrez, eds. 2013. *Site Selection and Carrying Capacities for Inland and Coastal Aquaculture. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland*. FAO Fisheries and Aquaculture Proceedings No. 21. Rome: FAO, 46 pp. Includes a CD–ROM containing the full document (282 pp.). www.fao.org/docrep/017/i3099e/i3099e00.htm.

Tookwinas, S. 2004. "Mitigation Plan on the Use of Mangroves for Aquaculture: Thailand." In *Promotion of Mangrove-Friendly Shrimp Aquaculture in Southeast Asia*, 160–167. Tigbauan, Iloilo, Philippines: Aquaculture Department, Southeast Asian Fisheries Development Center.

White, P., and N. Lopez. 2017. "Mariculture Parks in the Philippines." In "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture: A Handbook," edited by J. Aguilar-Manjarrez, D. Soto, and R. Brummett. Report ACS113536. FAO and World Bank, Rome. http://www.fao.org/3/a-i6834e.pdf.

Yücel-Gier, G. 2017. "Mariculture Parks in Turkey." In "Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture: A Handbook," edited by J. Aguilar-Manjarrez, D. Soto, and R. Brummett. Report ACS113536. FAO and World Bank, Rome. http://www.fao.org/3/a-i6834e.pdf.

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