5. Resource use and the environment

INTRODUCTION

Similar to other food producing sectors in the world, aquaculture relies upon the use of natural resources such as land and water. In addition, aquaculture requires seed and feed resources, and more intensive forms of aquaculture depend upon ancillary resources such as energy (fossil fuels, electricity, etc.). However, aquaculture typically uses less land or water area per unit of production in comparison with other sectors. The use of natural resources for aquaculture production requires appropriate management of the interactions between aquaculture and the environment during planning and implementation of activities, and this is essential for the sector's sustainability. The aquaculture–environment interactions and the issues related to resource use have been well documented in numerous publications (FAO/NACA, 1995; FAO, 1997; NACA/FAO, 2001a). While in the past, the main emphasis was placed on environmental interactions, it is now clear that for competent management of aquaculture, issues relating to socio-economics, human health and the assurance of food safety must also be adequately addressed.

Aquaculture is a diverse sector spanning a range of aquatic environments spread across the world. It utilizes a variety of production systems and species. While the impact of aquaculture on the environment cannot be generalized, it is important to recognize problems where they occur and ensure that they are redressed or ameliorated. Identified cases of environmental and natural resources interactions that have been negatively associated with aquaculture include:

- discharge of aquaculture effluent leading to degraded water quality (eutrophication, concern over red tides, low dissolved oxygen, etc.) and organic matter rich sediment accumulation in farming areas;
- alteration or destruction of natural habitats and the related ecological consequences of conversion and changes in ecosystem functions;
- competition for the use of freshwater;
- competing demands with the livestock sector for the use of fish meal and fish oil for aquaculture diets;
- improper use of chemicals raising health and environmental concerns;
- introduction and transmission of aquatic animal diseases through poorly regulated translocations;
- impacts on wild fisheries resources through collection of wild seed and brood animals; and
- effects on wildlife through methods used to control predation of cultured fish.

Over the past five years, considerable progress has been made in the environmental management of aquaculture, addressing many of these key concerns. Public pressure as well as commercial pressure or common sense has led the aquaculture sector to improve management, and increasingly it is recognized that aquaculture has positive societal benefits when it is well planned and well managed. In terms of environment–aquaculture interactions these include:

- more efficient use of energy and other natural resources than many other forms of animal production;

- an alternative source of aquatic animal protein which can be less environmentally damaging than some fishing and over fishing practices; and
- improvements in water and environmental quality through aquaculture farming systems and practices such as: integrated farming, low intensity herbivorous fish culture, seaweed and mollusc farming.

During the past decade, global awareness and sensitivity to the environmental issues related to aquaculture has increased significantly. As a consequence, policy and regulation governing environmental sustainability have been put in place in many countries, requiring aquaculture producers to comply with more stringent environmental mitigation/protection measures. In some countries these changes were even initiated by the aquaculture sector itself, usually within the more organized private industry sector to ensure its sustainability and protect operations from poorly managed activities. The private sector has made tremendous advances in the management of its activities and there are many examples of better management of farming systems that have reduced environmental impacts and improved efficiency, including profitability, in all regions.

In several countries, aquaculture producers are introducing environmental certification, either individually or in a coordinated manner, in order to credibly demonstrate that their production practices are non-polluting, non-disease transmitting and/or non-ecologically threatening. Some countries have already introduced state-mediated certification procedures, to certify that aquaculture products are safe to consume and farmed in accordance with certain environmental standards.

This chapter provides more information on the major issues highlighted above with a regional and global perspective, including significant advances in management and mitigation plus lessons learned during recent years. Food safety, aquatic animal health and transboundary issues are considered in more detail in separate sections (Chapter 3, Markets and trade).

EFFLUENTS FROM AQUACULTURE

Aquaculture, like many other human activities, produces wastes which, if not managed properly, may negatively affect the environment. In intensive aquaculture, a considerable amount of organic wastes are produced in the form of particulate and/or soluble substances (mainly the uneaten food, faeces and excreta) which increase biochemical oxygen demand, nitrates and phosphates in receiving waters. This may not necessarily be a problem as natural breakdown processes or dilution in the receiving waters can assimilate this, provided that natural waters are not overloaded, and the increased fertility of oligotrophic waters may even bring positive effects on the local ecosystem, enriching food availability for wild species.

The risk of negative impacts of aquaculture wastes are greatest in enclosed waters with poor water exchange rates, where excessive development of intensive aquaculture can lead to eutrophication and other ecosystem changes (e.g. algal blooms and low dissolved oxygen levels). This is typically site specific and occurs in slow moving rivers, lakes and shallow bays, when the nutrient loading is far higher than the carrying capacity of the ecosystem, usually as a result of over-crowding or poor water exchange.

***Farm density and intensification of operations* –** Although the number of individual business enterprises operating fish farms has sharply decreased in all major finfish producing countries in Western Europe over the past decade, the number of sites has remained largely unchanged or has decreased only marginally. For example, the two-and-a-half-fold increase in salmon production (298 000 to 730 000 tonnes) from 1994 to 2003 was attained largely from the use of more feed within the same number of sites thus increasing environmental pressure in these localities (Rana, 2006). Even though net loadings per tonne of production have declined significantly, such concentrated farming activity has resulted in an increase in organic and inorganic discharge of nutrients, thus creating a major challenge in environmental monitoring to the European salmon industry. Norway has a monitoring system in place – the MOM or Modelling-On growing fish farms–Monitoring (Hansen *et al*., 2001). Other countries such as Scotland and Chile have strong environmental regulations in place for salmon aquaculture, which address such requirements.

COURTESY OF SHELLFISH HEALTH UNIT, DFO, MONCTON, CANADA

Oyster racks in Canadian waters. Culture of molluscs is considered highly environmentally friendly as they do not require any inputs for growth and utilizes nutrients from the surrounding waters. Integrated mariculture is increasingly practiced with fish, molluscs and seaweeds cultured in close proximities.

Impacts of dissolved nutrients - In general the total amounts of N and P loading are linked with aquaculture intensity and with feed conversion factors. In Norwegian and Scottish coastal waters, around 55 percent and 17 percent, respectively, of all coastal phosphorus discharge was attributable to mariculture. These discharges, although only indicative, also contribute to the overall load from inland and coastal environments in some locations, together with discharges from agriculture, forestry, industry and domestic waste. However, its impact on regional nutrient loading is unclear and is likely to be negligible (Rana, 2006)**.** For example, it has been estimated that in the Mediterranean finfish aquaculture (UNEP/MAP/MED POL, 2004) N and P loading did not increase as production increased over the past several years. According to Karakassis, Pita and Krom (2005), N and P loading from aquaculture would be less than 0.1 percent of the total loading originating from agriculture and sewage.

Clearly on a global perspective, more research and integrated monitoring is needed to offer reliable environmental carrying capacity estimates of inland water bodies and coastal zones/areas. Such information is still needed to refine effective strategies for sustaining aquaculture through integration with other coastal or aquatic uses (GESAMP, 2001).

Mitigation measures through improved management **–** Mitigation of any problems associated with aquaculture effluents and wastes from inland or coastal facilities can take a variety of forms. In fish or shrimp ponds, the use of different types of filters and sedimentation ponds can greatly reduce nutrients loads on receiving waters. There are new shrimp pond management regimes using recirculation and high aeration to enable reduced water exchange, in some cases to almost zero discharge.

Improved feed management **–** Innovations in automated feeding technology and feed form/composition have significantly reduced feed inputs and effluent loads per unit of production, whilst maintaining productivity. In salmon farming over the past decade, feed conversion ratio has been steadily decreasing, from 1.5 to near 1.0 (Larrain, Leyton and Almendras, 2005). Such reduction implies less organic matter and nutrients discharged to the environment. However, other types of aquaculture (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 (FAO/GFCM, 2006).

In open-water fish cages waste products cannot be contained although the impact of effluents can be greatly reduced because of good water circulation. Through the use of good quality and stable feeds and by practising good feed management, it is possible to significantly reduce the impact of wastes in such environments. Selection of suitable sites with good water circulation and currents, and proper spacing of cages limits impacts on the water column and prevents excessive sedimentation of the seabed.


COURTESY OF FLAVIO CORSIN

Farmer checking feeding tray in a shrimp pond. Feeding trays are increasingly used in shrimp farming to check feeding efficiency and health of animals under culture. These devices make feeding more efficient and reduce pollution from excess feeding.

There are well documented impacts from the cage aquaculture of salmon in coastal fjords and lochs. There is considerable experience in mitigating impacts from aquaculture effluents in salmon farming. Smolt production in Chile is moving rapidly out of lakes, using fully re-circulated water systems, following similar techniques used in Norway and Denmark (Morales and Morales, 2006). There are also examples from sea bream and sea bass culture in the Mediterranean Sea and tilapia culture in freshwater lakes in Asia.

Most published studies concerning the impact of aquaculture wastes conclude the only significant impacts are localized effects from organic pollution on the sediments (Troell and Berg, 1997; Brooks *et al.,* 2003; Soto and Norambuena, 2004; Pitta *et al.,* 2005). Although eutrophication has been described as a potential impact, (Gowen, 1994) there are few studies that actually demonstrate this effect directly, may be due to the fact that most studies were done in large water bodies with high dilution effect where impacts are minimal (Aure and Stigebrandt, 1990). In highly loaded freshwater lakes, such as Lake Tal in the Philippines and reservoirs in West Java, eutrophication from cage culture and impacts on water have been documented (NACA/FAO, 2001b).

***Use of extractive aquaculture to reduce nutrient loadings* –** Aquaculture also provides opportunities for improving the aquatic environment. The extensive low input mollusc or seaweed systems remove nutrients from the culture environment (Neori *et al*., 2004). Effective integration of combinations of fed aquaculture and such "extractive" aquaculture practices can result in net increase of productivity and could mitigate against nutrient build up in the environment. Mixed culture of fish, molluscs and seaweeds practiced in the coastal bays of China is a good example. However the techniques require further development and improvement. Economics of such integrated systems also require careful examination. If densely located, even extractive aquaculture systems can cause negative impacts on the environment, especially on sediments, as a result of faecal and pseudofaecal accumulation.

***Managing the sector at an area level* –** Proper zoning accompanied by environmental impact assessments (EIA), including adequate evaluation of the carrying capacity of the environment as a prerequisite to establishing aquafarms are important tools in reducing environmental pollution in multiple use environments. Some countries are already applying these tools as requirements for aquaculture licensing, thus helping to reduce the negative environmental impacts of aquaculture and encourage establishing sites in suitable locations[1].

MODIFICATION OF COASTAL ECOSYSTEMS AND HABITATS

The issue of clearing mangroves for fish and shrimp ponds has largely abated over the years for many reasons. Foremost is the greater awareness on the importance of mangroves that has led many governments to impose either stricter regulations over their use or outright ban on further clearing although implementation may still be uneven among countries. Secondly, it has become increasingly clear that technically the mangrove is

[1] www.fao.org/figis/servlet/static?dom=root&xml=aquaculture/nalo_search.xml

not the best area for semi-intensive or intensive aquaculture and new farms are seeking areas behind the mangrove intertidal areas. Additionally, many countries are now attempting to implement the RAMSAR Resolution VIII.32 on "Conservation, integrated management, and sustainable use of mangrove ecosystems and their resources" (RAMSAR, 2002), which effectively protects fragile mangrove ecosystems worldwide. Finally, the attention given to mangroves and aquaculture had largely ignored the impacts of other uses such as agriculture, with various studies now showing that aquaculture globally accounts for less than 10 percent of the loss of this important coastal habitat.

COURTESY OF MOHAMED SHARIFF

Mangrove rehabilitation around shrimp ponds. Shrimp farming has been blamed for destruction of mangrove habitats. Many countries now ban mangrove clearance for aquaculture.

Using mangroves for aquaculture is a historical practice. In Southeast Asia, particularly Indonesia and the Philippines where the culture of milkfish has a long tradition, the mangrove area was considered an ideal site for brackishwater fish ponds because the ground elevation of such areas is low enough to be flooded naturally during high tide. Such attitude on mangroves was common throughout the world up to the 1970s, since "mangroves were generally considered as waste lands with little intrinsic value and their destruction was encouraged by government and planners" (Spalding, Blasco and Field, 1997). It was only during the 1980s at the height of widespread interest on shrimp farming that concern heightened over the destruction of mangroves. This appears to coincide with the development of large shrimp farms using mangrove areas in the western hemisphere, particularly in Latin America. So although most of the mangrove forests in Asia were originally cleared for fish and merely converted to shrimps much later, the destruction of mangrove forests is often still attributed largely to shrimp farming.

In most of Asia, not only has the further clearance of remaining mangrove areas for aquaculture been banned, but also many countries have embarked on replanting and restoration. Besides these, various attempts have been made to develop aquaculture in ways that do not cause damaged to mangroves (SEAFDEC, 2006; www.deh.gov.au/commitments/wssd/publications/mekong.html).

Africa, Madagascar, Mozambique and the United Republic of Tanzania have identified and zoned suitable areas for shrimp farming and Mozambique in particular has imposed strict environmental controls over these areas. Farms are required to treat effluent water and a large-scale and successful mangrove rehabilitation programme has been instituted for those areas where water supply canals have been built through mangrove swamps (Hecht, 2006).

In Latin America initially, the cultivation of shrimp affected mangrove areas in Colombia, Guatemala, Honduras, Nicaragua, Panama, Ecuador and Brazil. Nowadays, it is possible to see a degree of mangrove recovery thanks to better regulations for their protection, increasing awareness in the shrimp industry, and incentives for their restoration through replanting and maintenance measures. Some important initiatives that have taken place are the adoption of better management practices of shrimp farming (e.g. in Brazil) and the development of a mangrove atlas for the Brazilian north-east which provides information relevant for better management and use of the ecosystem (Parente Maia *et al.*, 2005).

Mangrove is not the only coastal ecosystem that may be affected by aquaculture. Untreated pond effluents can also potentially impact on coral reefs and sea grass communities, the latter has been well documented, here organic wastes from improperly located fish cages can rain down and smother such sensitive ecosystems. Freshwater marshes and wetlands that are often home or feeding grounds of birds are potential areas which might be improperly used for aquaculture without strict government controls. The awareness of the importance of conserving critical and fragile habitats has been growing. This has evidently reduced the deleterious use of critical habitats for aquaculture and led to the development of appropriate policies and regulatory measures in many producing countries, worldwide particularly in those were an environmental impact assessment is mandatory since fragile habitats are or should be clearly identified (GESAMP, 2001).

WATER AND LAND USE IN AQUACULTURE

Concerns regarding the use of land and water for aquaculture arise from problems of prioritization, as crops, especially staple crops such as rice, are often considered more important than fish, aquaculture development is perceived as a competition and/or a threat to agriculture. Urbanization and industrialization are starting to encroach on and reduce the area for aquaculture, particularly in places where there is no appropriate land-use zoning.

Challenges related to the utilization of water for aquaculture is often associated with the use of freshwater, which can also be used for crop irrigation and human use (consumption, bathing, etc.). Freshwater aquaculture can use significant volumes of freshwater, particularly in flow through systems, and this has led to speculation regarding whether aquaculture can afford to continue to use large volumes of freshwater for production purposes, in the face of increasing demands for water for human use. On the other hand, many freshwater ponds on Asian farms contribute to water conservation. This debate is rather complex, as in most cases aquaculture is not a significant consumptive user of water, since the water is returned to the system. However the quality of water may be modified in intensive operations. In some cases this has a positive benefit since this water can be used for irrigation of crops contributing to fertilization and production.

The risks of conflicts arise where freshwater is constrained (i.e. in arid countries or where freshwater is pumped from aquifers) and there is strong local competition for water. Again, aquaculture may not be a consumptive user and effective integration of the water uses can increase the net benefit for competing users (e.g. the use of good quality waste waters for aquaculture).

The use of marine waters for aquaculture (sea farming) also faces competition from other resource users; this is not typically competition for the water itself, but more for the use of marine or coastal areas for purposes other than aquaculture. Such competition comes from: fisheries, tourism, navigation, urban development, conservation of biodiversity, etc., and usually relates more to the spatial use of water by aquaculture than the quality or volume of water used. According to the FAO regional aquaculture trends reviews, some countries have started to restrict the use of land and water resources for aquaculture through effective land use planning and zoning (e.g. Chile, Mexico, China) (Morales and Morales, 2006 and NACA, 2006).

In terms of water use, there is a difference between the use of freshwater for aquaculture and the use of freshwater to manage salinity in brackishwater aquaculture, although the latter is highly discouraged and/or banned in many countries. However, multiple use of water for irrigation, agriculture and aquaculture is regaining attention. The productivity of integrated farms in many parts of Asia, particularly China, which takes advantage of the synergy between paddy and fish is a good example of such multiple uses.

COURTESY OF MATTHIAS HALWART

Rice-fish farming in Guyana. Rice-fish farming is mainly practiced in Asia. However, in the Caribbean countries the practice is now gaining momentum. Paddy farmers generate extra income by culturing fish in paddy fields and this integrated practice increases the water use efficiency.

In Egypt, only brackish and marine water and the lands that are deemed unsuitable for agriculture can be used for aquaculture, thus restricting the use of freshwater (El-Gayar and Leung, 2001). A rotating system utilizing a land portion for rice during the dry season and fish (or shrimp) during the wet season as practised in Asia can be considered an excellent way of optimizing land use based on "best use" as dictated by the season. A similar system exists in the southern United States where rice lands are used to produce crayfish during the winter months with the crayfish subsisting largely on the ratoon growth of the rice stalks (Olin, 2006).

Integrated irrigated aquaculture (IIA) is a concept which has been developed to maximize water use efficiency, particularly in Africa. The IIA development has the potential to increase productivity of scarce freshwater resources and reduce pressure on natural resources, particularly in the drought-prone countries of West Africa. Irrigated systems, floodplains and inland valley bottoms are identified as the three main target environments for IIA in West Africa. In irrigated systems, aquaculture is a non-consumptive use of water that can increase water productivity (e.g. rice-fish farming in Asia). Continuity of water supply, the effect of aquaculture on water conveyance and the use of agrochemicals are the main points of attention for aquaculture in irrigation systems (NACA, 2006 and Poynton, 2006).

River floodplains and deltaic lowlands also offer opportunities for integration of aquaculture. Food production can be enhanced by enclosing parts of these flooded areas and stocking them with aquatic organisms. Examples of community-based rice-fish culture in Bangladesh and Viet Nam show that fish production can be increased by 0.6 to 1.5 tonnes per hectare annually. Another example is the use of seasonal ponds in the wetlands surrounding Lake Victoria (East Africa) which are stocked with water and fish by natural flooding and are managed using locally available resources such as animal manures and crop wastes. These are all good management strategies for better land and water use within an integrated framework.

In Saudi Arabia, irrigation water is used initially for tilapia farming to avoid contamination from the pesticides used in the agricultural crops. The situation is different when freshwater is used for brackishwater aquaculture. Once mixed with seawater, it cannot be used for other purposes. What makes the practice worse is when groundwater is extracted by pumping for aquaculture. Due to the large volumes required, this can cause saltwater intrusion to the aquifer rendering it unfit for agriculture and drinking (Poynton, 2006).

Over the years, these concerns on land and water use in aquaculture have been addressed carefully by many producing countries. Land-use planning, zoning, efficient use of water resources, multiple use of water, etc., have been practised in many countries at different scales. Some examples of partial or total recirculation of water for shrimp farming are now evident in some countries. Although expensive, recirculation or closed-water systems have proven their merit on improved biosecurity, thus reducing disease.

Aquaculture also offers opportunities for the alternative uses of land and waterbodies that suffer from salinization after irrigation or that are just not good enough for agriculture. For example in Eastern Europe most of the pond fish farms were built on areas that cannot be used for efficient agricultural production due to the low quality of the soil. There are also some large inland areas that are inundated regularly. Fish ponds or reservoirs have been constructed in some of these areas (FAO/NACEE, 2006).

In coastal areas, aquaculture can have conflicts with tourism and recreational activities; an example is in the Mediterranean and Adriatic seas. Although the fish-farming industry is now looking for more suitable space for relocation or expansion, the tourism and recreational industry is restricting this, creating a conflict of interest. Some countries in the region now implement good land-use planning and environmental impact assessment (EIA) procedures for development activities (including aquaculture) which avoids such conflicts, while improving the social impacts and economic revenue (Rana, 2006).

In other countries such as Chile and Mexico the main potential conflicts for water and space use particularly in fish farming are with small-scale fisheries, however, aquaculture zoning has been established to minimize or avoid such conflicts (Morales and Morales, 2006).

FEEDING FISH WITH FISH AND OTHER FEED ISSUES

One argument against aquaculture, which is often raised, is the use of low-cost fish species such as sardines, herrings or anchovies (low-value freshwater fish in some instances) as feed (fishmeal, fish oil and trash fish) to produce a higher-value carnivorous species such as tuna, grouper, crabs and shrimps. There are two major concerns. First, with this practice, carnivorous fish aquaculture does not contribute to global fish production, since every kilogram of farmed fish requires more than 1 kg of feed fish species depending upon whether raw fish is used as direct feed or in fishmeal form as a feed ingredient. Second, converting low-value species into a high-value species can make farmed fish prices beyond the reach of the poor and therefore has food security implications. However, despite such arguments, aquaculture production of fish low in the food chain, such as carps, is still greater than carnivorous species, and so aquaculture is clearly a net producer of aquatic products and a contributor to global food security. On the other hand, the production of high-value commodities such as salmon, while not providing food for the poor, in most cases are providing jobs and could have a large social impact (Morales and Morales, 2006).

In the ecological sense, converting several units of fish biomass to one unit of fish biomass is inefficient, although it is of course a perfectly natural phenomenon when shifting from one trophic level to another. Yet, aquaculture is an economic activity where efficiency is measured in monetary terms, not in terms of biomass or energy conversion, although such concepts should permeate more. Thus the use of fish in aquaculture, either in fresh or fishmeal form, will likely continue for as long as it is economically advantageous to do so.

Feed accounts for about 60–80 percent of operational costs in intensive aquaculture, while feed and fertilizers represent about 40–60 percent of the total cost of aquaculture production in semi-intensive aquaculture systems. Fertilizers and feed resources will, therefore, continue to dominate aquaculture needs. The importance of dietary input in aquaculture can further be emphasized by the fact that about 22.8 million tonnes or 41.6 percent of total global aquaculture production in 2003 was dependent upon direct use of feed either in the form of a single dietary ingredient, home-made aquafeed or by the use of industrially manufactured aquafeeds (FAO, 2005). In 2003, 19.5 million tonnes of compound aquafeed was estimated to be produced and the primary users of these aquafeed were non-filter-feeding carps, marine shrimp, salmon, marine finfish, tilapia, trout, catfish, freshwater crustaceans, milkfish and eels (FAO, 2006).

TABLE 5
Estimate of trash fish used to produce freshwater and marine species in Vietnam.

Species	Production (mt)	%using trash fish	FCR	Moist/wet feed (t)	Trashfish (t)	
					Min	Max
Pangasius catfish	180 000	80%	2.5	360 000	64 800	180 000
Shrimp (*Penaeus monodon*)	160 000	38%	4.75	287 280	71820	143 640
Marine fishes (grouper)	2 000	100%	5.9	11 800	11 800	11 800
Lobster (*P. ornatus*)	1 000	100%	28	28 000	28 000	28 000
Total				687 080	176 420	363 440

(Source: A Survey of Marine Trash Fish and Fish Meal as Aquaculture Feed Ingredients in Vietnam. P. Edwards, Le Anh Tuan & G L Allen. ACIAR. 2004).

Trash fish used for inland, coastal and overall aquaculture in Viet Nam were estimated to be between 64 800 and 180 000 t; between 72 000 t and 144 000 t; and between 177 000 t and 364 000 t, respectively.

Although the feed-based aquaculture sector is highly dependent upon capture fisheries for sourcing feed inputs, either in the form of fishmeal, fish oil and so called "low-value trash fish", the major consumers of fishmeal and fish oil are carnivorous fish and crustaceans. It has been estimated that about 53 percent of global fishmeal and 87 percent of fish oil was consumed by salmonids, marine fish (in general) and marine shrimp in 2003.

There are three main types of raw materials used for producing fishmeal: (a) trimmings from fish processing plants, (b) bycatch from fishing, and (c) fish species, which occur in large volumes but do not have a demand as direct human food. The anchoveta caught in the upwelling area off the southern Pacific coast of South America is a good example of such species. Along with anchoveta as a major raw material for fishmeal are capelin, blue whiting, sandeel, sprats, menhaden and Alaskan pollack in the northern hemisphere. Since 1985, global production has stabilized at 6 to 7 million tonnes of fishmeal and one million tonnes of fish oil (IFFO, 2006).

This means that the expanding aquaculture and livestock sectors will be competing for a resource that is not increasing – a situation that has been referred to as the "fish meal trap" (FAO, 2002). Under a situation of apparently limited supply of fishmeal and fish oil, and assuming little or no improvement in the efficiency of use of fishmeal and fish oil, the expansion of some types of aquaculture could be constrained if not altogether stopped. Even with stable (neither increasing nor decreasing) supplies of raw fish for fishmeal production, it is also argued that the growing demand for fishmeal will continue to drive the price of fishmeal and fish oil upwards. Upon reaching a certain price level, the use of fishmeal and fish oil may no longer be financially viable. This highlights the need to reduce reliance on fishmeal and to improve the efficiency of use, and considerable research is currently underway in many producing countries. Along these lines, the livestock sector appears to have made the greatest advances, which it has been forced to do because of economic factors.

Natural phenomena affecting the environment and feeds availability/ quality - The El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific having important


COURTESY OF FLAVIO CORSIN

Preparing trashfish for feeding cage cultured freshwater fish in Cambodia. Use of trashfish for aquaculture has become a point of discussion. It is more so when food grade fish are fed to culture high value marine species such as grouper.

consequences for weather around the globe. The Peruvian anchovy fishery, a major fishmeal component (which represented over a quarter or 28.5 percent of the total estimated marine fisheries landings destined for reduction in 2003) is extremely vulnerable to the El Niño phenomenon. Over the past century the fishery for Peruvian anchoveta has undergone catastrophic declines after every strong El Niño event, with landings over the last 30 years ranging from a high of 13 million tonnes in 1970 to under 0.1 million tonnes following the 1982–1983 El Niño (the strongest this century), and landings declining drastically after every major event. However, the Peruvian anchovy populations have demonstrated to have a high capacity to recover from "El Niño" type of events provided these are followed by more favourable environmental conditions and proper fisheries management is in place. On the other hand other species have been incorporated into the fishmeal processing in the area (such as horse mackerel and sardines) which makes fishmeal production more resilient to these events and to the effects of single species' abundance variability. Also, the monitoring and forecasting capabilities of events such as el Niño have improved and, therefore, fisheries management finds or should find itself in a better position to respond and to cope with these changes.

Fishmeal can be replaced by vegetable protein, but results in increased costs in the form of enzymes to remove antinutritional factors and amino acids to improve the nutritional profile (Tacon, 2005). Nevertheless, fishmeal is still relatively available and its use will continue until availability becomes seriously constrained. The replacement of fish oils has been a more challenging task because of the difficulty in finding alternative sources of omega 3 molecules. However, the rising prices of both fishmeal and oil are driving research in the feed industry towards finding substitutes (FAO, 2006).

Global trends indicate that the high-value aquaculture sector is growing and this sector is the most reliant on feeds containing fishmeal and fish oil. Within the freshwater aquaculture sector, there are likely shifts in feeding and feed composition since it has a greater opportunity to use non-marine sourced feed ingredients (particularly slaughterhouse wastes, brewery wastes and agricultural milling by-products). The higher market price of marine cultured fish and crustaceans will enable this part of the sector to afford higher fishmeal prices as demand increases.

While some countries in the world produce adequate quality commercial fish feeds for aquaculture, many depend on imports from countries within or outside the region. The evolution and development in fish feed manufacturing in aquaculture has made good progress in all regions, perhaps except Africa. As mentioned above there are many ongoing studies aiming to reduce or substitute fishmeal with cheaper more available protein.

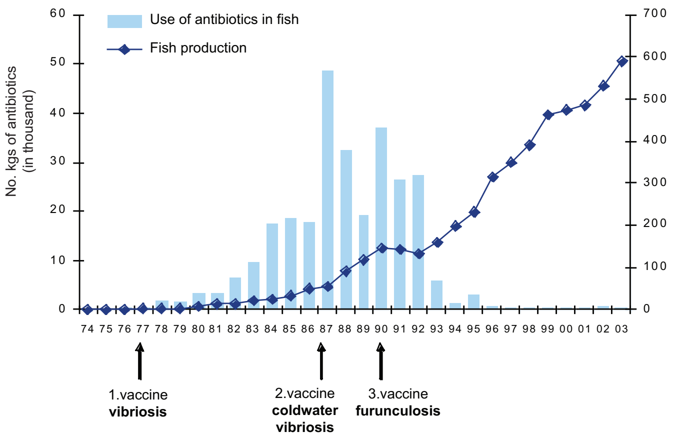
CONTAMINANTS AND RESIDUES IN AQUACULTURE

Aquaculture practices, particularly intensive forms, sometimes require the use of therapeutics (commonly referred to as drugs), 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, chemicals, solutions, and compounds; not all of these may be used at any particular aquaculture site. Other treatments may be needed against hazards such as predators and fouling of marine cages.

Therapeutics are sometimes necessary for specific and identified uses in aquaculture. However, they should be used responsibly and under adequate control through appropriate regulation. While awareness building and education of farmers and processors on the responsible use of therapeutics is important, pharmaceutical manufacturers and dealers, feed manufacturers, and other relevant service providers should also fully cooperate in the efforts to regulate therapeutic use in aquaculture. Many governments around the world have introduced changes or tightened national regulations on the use of therapeutics in general, and within the aquaculture sector in particular.

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, as with salmon in Norway; the sharp decline took place after the vaccine against furunculosis caused by the bacteria *Aeromonas salmonicida* was developed (Midtlyng, 2000). Yet more efforts should be placed on research to develop better health management for finfish and crustaceans in aquaculture.

FIGURE 1
Effect of vaccination on the use of antibacterials in Norway 1974 – 2003



Source: Subasinghe and Arthur, (eds.), 2005

Use of antibacterials in aquaculture is a controversial issue. Many anitbacterials are banned for the use in aquaculture. However, alternate health management procedures such as development of effective vaccines could significantly reduce the use of antibacterials and also increase production. The best example is Norway.

Excellent experiences were gained and positive results obtained by using the “cluster management” concept in bringing small-scale shrimp farmers together to manage their ponds using better management practices. This has reduced the use of antibiotics and completely removed the need to use banned antibacterial and veterinary drugs. (See Chapter 3, Markets and trade.)

The use of therapeutics can result in the presence of residues in the aquaculture products. Most of the presently permitted therapeutics are relatively safe and should not harm the environment outside the fishpond/fish cage as long as these are used properly. Better management practices, discussed at length in other chapters of this review, should significantly reduce the use of chemicals and other substances of any risk. In general, the use of these chemicals or pesticides has dwindled due to stricter regulation by governments and the stringent requirements of the export trade.

Although antibiotics have also been recommended and used as disinfectants in fish handling, this practice has proven to be non-hygienic, and is generally not approved by the fish inspection services. Antibiotics have not always been used in a responsible manner in aquaculture, and in a number of reported situations, the control of the use of antibiotics did not provide a proper assurance of the prevention of risks to humans. Organisations including FAO, WHO, the World Organisation for Animal Health (OIE) and a number of national governments are attempting to restrict use of antibiotics in all production sectors, as the potential risks to public health is a particular concern.

Contamination of aquaculture products – The other side of the coin is the contamination of aquaculture products due to other human activities. This has become an issue of public concern particularly after the publication of information referring to contamination of farmed salmon through fishmeal with dioxins, PCBs (polychlorinated biphenyls) and other chemicals, mostly pesticides (Hites *et al*., 2004). Even though the overall benefits of eating salmon and other seafood products are overriding, consumers are now more aware and are increasingly demanding safer products. Many human activities can affect aquaculture, the most important being sewage outflows, which can cause bacterial contamination and promote eutrophication, enhance algal blooms, etc., and industrial outflows, which may carry contaminants that affect aquaculture performance or may be picked up as residues in aquaculture products. The use of pesticides and fertilizers in agriculture can cause substantial damage to aquaculture. The deterioration of the aquatic environment by industrial effluents is seen as a major obstacle to further aquaculture development in certain coastal areas and is one of the reasons for pushing aquaculture offshore. Fishmeal contamination in industrialized regions of the world is also a major problem in the use of feed resources for aquaculture.

USE OF WILD-CAUGHT BROODSTOCK, POST-LARVAE AND FRY

Most freshwater species used in aquaculture are now hatchery bred, although wildcaught juveniles are still used in aquaculture in some parts of the world. Hatcheries in most countries are now capable of meeting demand for quality seed of freshwater species. The dependence of aquaculture on wild-caught seed is thus gradually diminishing and will most likely be limited to mature fish to be used in breeding programmes to improve the quality of broodstock. However, in the ornamental fish industry, there are a number of species that are still caught as juveniles for exports.

The situation is different in the marine and brackish environments where the culture of a range of species (grouper, mangrove crab, shrimp, tuna, eel, etc.) still depends on wild-caught broodstock or seed.

The use of wild-caught species in aquaculture is seen as causing negative impacts on aquatic biodiversity. One example is the black tiger prawn, *Penaeus monodon*. After years of culture in Asia and Latin America, almost all postlarvae are now hatchery produced. However, *P. monodon* aquaculture still almost fully depends on wild-caught breeders. The continued use of wild-caught broodstock as parent material makes the shrimp industry vulnerable to deterioration of seedstock quality, including susceptibility to pathogens. It is under such circumstances that many East and Southeast Asian producers have shifted to the Pacific white shrimp, *Penaeus vannamei*, due to the ready commercial availability of "specific pathogen free" (SPF) broodstock. It is worth noting here that the ability to produce SPF *P. vannamei*, has now sparked considerable interest giving way to research and development to produce SPF stocks of many other species and these are already starting to come into commercial production (e.g. *P. chinensis*) (Briggs *et al*., 2005).

In addition to its impact on biodiversity, massive exploitation of natural fry stock also results in inadvertent collection of the fry of non-target species and therefore has the potential of reducing recruitment to fisheries. This affects the catch and income of small-scale fishers dependent on the affected species. However, in certain instances an abrupt and complete ban on the gathering of natural fry stock is not without social cost. This again is true in *P. monodon* particularly in South Asia. In Bangladesh, hundreds of thousands of poor fishers, especially women, are dependent on the gathering of natural *P. monodon* postlarvae from the Sundarbans. The growth of the shrimp aquaculture industry has been a boon to these poor coastal families. A similar situation prevailed in Ecuador, however, the emergence of hatchery-bred clean postlarvae has resulted in the almost complete cessation of this activity as farms prefer the hatchery-raised postlarvae due to the more certain health status.

The culture of several marine finfish species and a few high-value crustacean and mollusc species are still reliant on wild-caught seedstock. In most cases this is due to the lack of reliable mass production of seed in hatcheries. Examples of this are the mangrove crab (*Scylla* spp.), several grouper species (*Epinephelus* spp.) and the coral trout (*Plectropomus leopardus*).

As hatchery-produced milkfish (*Chanos chanos*) fry can now fully support industry needs, the only reason wild-caught fry are still being gathered is because it is a livelihood option of poor fishers. The technology for propagating mangrove crabs has been developed and it is expected that, as the demand for crab juveniles outstrips the supply of natural stock, investment in crab hatcheries will become more and more attractive. The same situation is true for some grouper species; the humpback grouper, *Cromileptes altiveles,* is now produced commercially in Indonesia. A good example of a candidate for captive production is the Napoleon wrasse, *Cheilinus undulates,* which is now listed in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), making the trade in wild-caught fish illegal. This commands a very high market price and can only be legally traded if demonstrated from aquaculture origin.


COURTESY OF MICHAEL PHILIPS

Napoleon wrasse (Cheilinus undulates). *Although a popular expensive food fish species in South East Asia, this fish is now listed in CITES making the trade in wild caught fish illegal. Captive breeding of this species is now well established.*

In countries where wild-caught fish are used in aquaculture, in some instances, there is legislation governing the process. In Egypt, the government, through the General Authority for Fisheries Research and Development (GAFRD) of the Ministry of Agriculture and Land Reclamation, licences and controls fry fishing for aquaculture. It also operates official fry collection centres. However, while fry collection is controlled, the control over prices has given rise to a black market in fry. This has made management of the fry resources difficult as the amount of fry collected can be four to five times the official figures.

It is likely that the sector's dependence on wild-caught seed stocks and broodstocks is going to be reduced significantly. Equally, introduction of proper broodstock management in aquaculture will also contribute to enhance depleted wild stocks, thereby contributing to their conservation.

EFFECTS ON BIODIVERSITY

No development process or intensive food production activity can ignore its potential impacts on biodiversity and aquaculture is no exception in this regard. Yet aquaculture could use biodiversity from a biotechnological perspective and through the simple offer of new species for culture.

Aquaculture can affect local biodiversity in many ways. As mentioned earlier the use of wildcaught fry is still common for some particular marine species. Repeated fishing for the juveniles of certain species can drastically alter species composition by preventing some of them from bring recruited into the reproductive population.

The movement of seedstock within a country or between countries may significantly alter the genetic characteristics of local stocks of the same species due to inevitable escapes and/or stock enhancement practices such as those reported for salmonid stocks in North America, Europe and South America (Naylor *et al*., 2005). Likewise the escape of alien species such as salmon and tilapia can have deleterious effects on biodiversity. A recent review (Canonico *et al*., 2005) on the effects of tilapia indicates that, as alien species, they are highly invasive and exist under feral conditions in every region in which they have been cultured or introduced. On the other hand, a review on impacts on tilapias as alien species in Asia and the Pacific (FAO, 2004), based on experiences in continental Asia, points out that there is no objective evidence to show that tilapias have negatively impacted on biodiversity in this region. Furthermore, these authors argue that tilapias tend to occur in degraded habitats arising from other human activities either directly or indirectly, which thus makes them unsuitable for indigenous species. However, the situation in some Pacific and Micronesian islands is evidently different.

Nevertheless, concern is increasing over the use of alien species in aquaculture. There is often apprehension that these, if allowed to escape, can establish spawning

Tilapia nests in Kiribati. Tilapias are successful introduced species in many parts of the world. It has also caused some environmental concerns, one of which is the prolific nesting and reproduction of the fish. This phenomenon has contributed to general rejection of this species as a candidate aquaculture species in the Pacific Micronesia.

populations in the country of introduction and dislodge native species from established food niches or worse become a pest. Equally, exotic species that do not establish reproducible populations could create short-term impacts due to other interactions with native species and populations. Clearly, a precautionary approach needs to be adopted with regard to the use of alien species for aquaculture purposes, particularly regarding biodiversity conservation. As a response, many countries have adopted specific regulations to prevent and implement mitigation/ control measures for escaped fish; this is particularly the case for salmon (Naylor *et al*., 2005).

Organic loading from cage or pen aquaculture is frequently cited as causing a decrease in bottom biodiversity. Although such effects are more local as there is usually a rapid recovery beyond the farms shade (Brooks *et al*., 2003), in some cases the impacts could have broader consequences; for example, when the affected habitat sustains high biodiversity and species refuge as is the case of seagrass beds (UNEP/ MAP/MED POL, 2004). Better planning, careful siting and improved construction and management practices can significantly reduce such negative impacts.

Impacts of aquaculture on biodiversity have been relatively exaggerated compared with effects of other productive sectors such as agriculture, and in most instances effects are linked to the escape of alien species or alien stocks, even though firm evidence is often not provided. Very often, habitat changes and degradation which have been brought about by non-aquaculture related activities that affect indigenous stocks and biodiversity precede those potentially connected to aquaculture and may even facilitate the latter. As aquaculture practices become increasingly responsible perceived impacts on biodiversity should decline.

There are a range of genetic improvement technologies available to aquaculturists from traditional animal breeding to genetic engineering. The use of genetically modified organisms (gene transfer technology) is controversial in most regions due to concerns about environmental and human health risks. There is much debate, even among scientists, on the degree of environmental risk associated with genetically modified organisms. However, most informed sources agree that, with the current set of genes that are being engineered for use in aquaculture, the risks to human health are minimal.

ENERGY AND RESOURCE USE EFFICIENCY

Aquaculture as an economic enterprise is sensitive to changing energy costs, particularly in more intensive systems. While energy use is typically for pumping, water circulation, aeration and lighting, transport and refrigeration are not minor uses. Fuel subsidies could improve economic viability of aquaculture, however, as a result of the rise in energy costs, aquaculture is driven to become more efficient and innovative. This is probably one of the largest challenges to intensive aquaculture, particularly to water recirculation systems which are more environmentally friendly as they reduce nutrient outflows, disease risks and escapees, etc. but with higher energy costs. Research and technology development should focus on such challenges. There is also a need for addressing the global energy costs of aquaculture products along the full life cycle of the process (Troell *et al*., 2004) in order to put aquaculture within an ecosystem context and also to help decision making regarding alternative enterprises or activities in a local area. Often optimization procedures are the best approach and farmers on intensive production systems, particularly for high-value commodities such as shrimp and salmon, have been adopting such approaches. Nevertheless optimization on aquaculture production with an energy saving perspective should be widely adopted at all production scales and more training and organization for small farmers are potential ways to achieve it. It is a paradox that as aquaculture systems evolve to reduce the impact on the environments in which they are placed, there are corresponding increases in the energy requirements needed to deal with increased production intensity and effluent treatment.

PROGRESS IN ENVIRONMENTAL MANAGEMENT OF AQUACULTURE

Several initiatives and advances in aquaculture environmental management have been cited. These measures suggest that mitigating environmental problems requires concerted action among public and private sectors. Although considerable progress has been made in recent years, a lot more challenges remain for both sectors to improve the overall environmental performance of aquaculture. The demand to improve will continue, due to increased pressures on aquatic resources, and as consumers, governments and the international community focus on the environmental impacts of aquaculture. Some examples from Asia addressing shrimp farming are presented in Chapter 3.

Key farm-level indicators of environmental sustainability of marine fish farming have been the increased use of fallowing, improved cage design to minimize escapees and reduced usage of antibiotics. There is more effective enforcement of regulations throughout the world, although these measures are targeted at the farm level. Regulations appear to be stringent in those countries where the growth of aquaculture has been most rapid and producing high-value commodities. In many countries the industry has taken the lead to respond to the environmental pressures, mostly driven by market forces.

Coastal management tools are available with relevant case studies and strong scientific support and information (GESAMP, 2001). Yet the implementation of integrated coastal management has not been widely successful partly because of the lack of public/stakeholders involvement and interest, and limited resources. Within such an approach there is a wide range of possibilities to integrate aquaculture to other coastal uses as well as integrating different aquaculture practices in order to better use nutrients, improve productivity and decrease outflow impacts (Neori *et al*., 2004). The establishment of permanent monitoring programmes to evaluate external factors affecting aquaculture as well as the impacts of aquaculture on the environment would help to improve the management of the sector.

All regions of the world show keen interest in coordinated work amongst official institutions and farmer groups to address environmental issues, including integrating codes of conduct and regulations. The recent series of national reviews by FAO entitled National Aquaculture Legislation Overview (NALO)[2] showed that during the last decade a large number of countries have incorporated specific regulations to promote environmental management of aquaculture. Government reports on the progress of implementation of the Code of Conduct for Responsible Fisheries indicate that, worldwide, efforts are being taken to improve policy and regulatory frameworks supporting sustainable aquaculture development and reducing the sector's environmental impacts.

---

[2] http://www.fao.org/figis/servlet/static?xml=nalo.xml&dom=collection&xp_nav=1

It is of critical importance that industry and research are effectively linked in those areas where environmental management and performance can be improved, for example research on better siting approaches, better diets and less expensive protein sources; technological innovations on feed manufacturing and efficient use of energy. More research is needed for the implementation of integrated aquaculture at larger production scales followed by training and extension so that the farmers are able to implement these approaches effectively. Capacity building is important particularly to develop and implement better management practices. Also more effective communication is needed at all levels both to share experiences in better management of the sector to all concerned and create dialogue and partnerships to improve understanding and find solutions to the pressing environmental issues affecting the development of this important food producing sector.

REFERENCES

Aure, J. & Stigebrandt, A. 1990. Quantitative estimates of eutrophication effects on fjords of fish farming. *Aquaculture*, 90: 135-156.

Briggs, M., Funge-Smith, S., Subasinghe, R.P. & Phillips, M. 2005. Introduction and movement of two penaeid shrimp species in Asia and the Pacific. FAO Fisheries Technical Paper. No. 476. Rome, FAO. 2005. 78p.

Brooks, K.M., Stierns, A.R., Mahnken, C.V.W. & Blackburn, D.B. 2003. Chemical and biological remediation of the benthos near Atlantic salmon farms. *Aquaculture,* 219: 355-377.

Canonico, G.C., Arthington, A., McCrary, J.K. & Thieme, M. 2005. The effects of introduced tilapias on native biodiversity. *Aquatic Conserv. Mar. Freshw. Ecosyst.*, 15: 463-483.

De Silva, S.S., Subasinghe, R.P., Bartley, D.M. & Lowther, A. 2004. *Tilapia as alien aquatics in Asia and the Pacific: a review*. FAO Fisheries Technical Paper. No.453. Rome, FAO. 65pp.

El-Gayar, O.F. & Leung, P. 2001. A multiple criteria decision making framework for regional aquaculture development. *Eur. J. Oper. Res.*, 33: 462-482.

FAO Inland Water Resources and Aquaculture Service. 1997. *Review of the state of world aquaculture: environment and sustainability*. FAO Fisheries Circular. No. 886, Rev.1. Rome. 163 pp.

FAO. 2002. *Use of fishmeal and fish oil in aquafeeds: further thoughts on the fishmeal trap*, by M.B. New & U. N. Wijkstrom. FAO Fisheries Circular. No. 975. Rome.

FAO. 2005. *Fishstat Plus: Universal software for fishery statistical time series. Vers. 2.30*. Fisheries Department, Fishery Information, Data and Statistics Unit. Rome (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

FAO/Network of Aquaculture Centres in Central and Eastern Europe. 2006. *Regional review on aquaculture development trends. 5. Central and Eastern Europe – 2005*. FAO Fisheries Circular. No. 1017/5. Rome, FAO. 97 pp.

FAO/GFCM. 2006. *Report of the experts meeting for the re-establishment of the GFCM Committee on Aquaculture Network on Environment and Aquaculture in the Mediterranean. Rome, 7–9 December 2005*. FAO Fisheries Report. No. 791. Rome. 60 pp.

FAO/NACA. 1995. *Regional study and workshop on the environmental assessment and management of aquaculture development* (TCP/RAS/2253). NACA Environment and Aquaculture Development Series No. 1. Bangkok. 492 pp.

GESAMP. 2001. *Planning and management for sustainable coastal aquaculture development*. Rep. Std. GESAMP No. 68. 90 pp.

Gowen, R.J. 1994. Managing eutrophication associated with aquaculture development. *J. Appl. Ichthyol.*, 10: 242–257.

Hansen, P.K., Ervik, A., Schaanning, M., Johannessen, P., Aure, J., Jahnsen, T. & Stigebrandt, A. 2001. Regulating the local environmental impact of intensive, marine fish farming - II. The monitoring programme of the MOM system (Modelling-Ongrowing fish farms-Monitoring). *Aquaculture*, 194: 75-92.

Hecht, T. 2006. *Regional review on aquaculture development. 4. Sub-Saharan Africa – 2005*. FAO Fisheries Circular. No. 1017/4. Rome, FAO. 96 pp.

Hites, R.A., Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A. & Schwager, S.J. 2004. Global assessment of organic contaminants in farmed salmon. *Science*, 303: 226-229.

IFFO. 2006. *Fishmeal industry overview*. International Fishmeal and Fish Oil Organization (available at www.iffo.org).

Karakassis, I., Pitta, P. & Krom, M.D. 2005. Contribution of fish farming to the nutrient loading of the Mediterranean. *Scientia Marina,* 69: 313–321.

Larraín, C., Leyton, P. & Almendras, F. 2005. Aquafeed country profile – Chile and salmon farming. *International Aquafeed*, 8(1): 22-27.

Midtlyng, P.J. 2000. Vaccination in salmonid aquaculture: a review. *In*: M. Fingerman & R. Nagabhushnam, eds. *Recent Advances in Marine Biotechnology*. Vol. 5. *Immunobiology and pathology*, pp. 227-242. Enfield, NH, USA, Science Publishers.

Morales, Q.V.V. & Morales, R.R. 2006. *Síntesis regional del desarrollo de la acuicultura. 1.América Latina y el Caribe – 2005/Regional review on aquaculture development.1. Latin America and the Caribbean – 2005*. FAO Circular de Pesca/FAO Fisheries Circular. No. 1017/1. Roma/Rome, FAO. 177 pp.

NACA/FAO. 2001a. *Aquaculture in the third millennium. Technical proceedings of the conference on aquaculture in the third millennium, Bangkok, Thailand, 20-25 February 2000*, eds., R.P. Subasinghe, P.B. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur. Bangkok, NACA and Rome, FAO. 471pp.

NACA/FAO. 2001b. Human resources development for sustainable aquaculture in the new millennium, plenary lecture IV, by S.S. De Silva, M.J. Philips, Y.S. Sih & X.W. Zhou *In*: R.P. Subasinghe, P.B. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. *Aquaculture in the third millennium. Technical proceedings of the conference on aquaculture in the third millennium, Bangkok, Thailand, 20-25 February 2000*, pp.43-48. Bangkok, NACA and Rome, FAO.

Naylor, R., Hindar, K., Flaming, I.A., Goldburg, R., Williams, S., Volpe, J., Whoriskey, F., Eagle, J., Kelso, D. & Mangel, M. 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *BioScience,* 55: 427-473.

Neori, A. Chopin, T., Troell, M., Buschmann, A.H., Kraemer, G.P., Halling, C., Shpigel, M. & Yarish, C. 2004. Integrated aquaculture: rationale, evolution and state of the art emphasizing sea-weed biofiltration in modern mariculture. *Aquaculture,* 231: 361-391.

Network of Aquaculture Centres in Asia-Pacific. 2006. *Regional review on aquaculture development. 3. Asia and the Pacific – 2005*. FAO Fisheries Circular. No. 1017/3. Rome, FAO. 97 pp.

Olin, P.G. 2006. *Regional review on aquaculture development. 7. North America – 2005*. FAO Fisheries Circular. No. 1017/7. Rome, FAO. 25 pp.

Parente Maia, L., Drude de Lacerda, L., Hislei Uchôa Monteiro, L. & Marques e Souza, G. 2005. *Atlas dos Manguezais do Nordeste do Brasil: Avaliação das áreas de manguezais dos Estados do Piauí, Ceará, Rio Grande do Norte, Paraíba e Pernambuco*. Document of Universidade Federal do Ceará, Instituto de Ciências do Mar, e Sociedade Internacional Para Ecossistemas de Manguezal – Isme-Br, 51pp.

Pitta, P.A., Apostolaki, E.T., Giannoulaki, M. & Karakassis, I. 2005. Mesoscale changes in the water column in response to fish farming zones in three coastal areas in the Eastern Mediterranean Sea. *Estua. Coast. Shelf Sc.*, 65: 501-512.

Poynton, S.L. 2006. *Regional review on aquaculture development. 2. Near East and North Africa – 2005*. FAO Fisheries Circular. No. 1017/2. Rome, FAO. 79 pp.

RAMSAR. 2002. *Wetlands: water, life, and culture***.** 8th Meeting of the Conference of the contracting parties to the convention on wetlands (Ramsar, Iran, 1971) Valencia, Spain, 18-26 November 2002.

Rana, K. J. In press. *Regional review on aquaculture development. 6. Western Europe – 2005*. FAO Fisheries Circular. No. 1017/6. Rome, FAO.

SEAFDEC AQD. 2006. *Mangrove-friendly shrimp culture: an ASEAN-SEAFDEC project* (available at www.mangroveweb.seafdec.org.ph).

Soto, D. & Norambuena, F. 2004. Evaluating salmon farming nutrient input effects in Southern Chile inner seas: a large scale mensurative experiment. *J. Appl. Ichthyol*., 20: 1-9.

Subasinghe, R.P. & Arthur, J.R. (eds.). 2005. *Regional workshop on preparedness and response to aquatic animal emergencies in Asia. Jakarta, Indonesia, 21-23 September 2004.* FAO Fisheries Proceedings. No. 4. Rome, FAO. 2005. 178 pp.

Tacon, A. 2005. *State of information on salmon aquaculture feed and the environment*. Salmon Dialog Report, WWF (available at www.worldwildlife.org/cci/dialogues/salmon.cfm).

Tacon, A.J.C., Hasan, M.R. & Subasinghe, R.P. 2006. *Use of fishery resources as feed inputs for aquaculture development: trends and policy implications*. FAO Fisheries Circular. No. 1018. Rome, FAO.

Troell, M. & Berg, H. 1997. Cage fish farming in the tropical Lake Kariba, Zimbabwe: impact and biogeochemical changes in sediment. *Aquacult. Res*., 28: 527-544.

Troell, M., Tyedmers, P., Kautsky, N. & Ronnback, P. 2004. *Aquaculture and energy use*. Encyclopedia of Energy, Vol. 1. pp.97-108. Elsevier.

UNEP/MAP/MED POL. 2004. *Mariculture in the Mediterranean*. MAP Technical Reports Series No. 140. Athens, UNEP/MAP.