Sustainability and Environmental Management of Aquaculture

In the recent past sustainability and the environmental management of aquaculture programmes have become deciding factors in aquaculture development in both developing and developed countries. Although auto pollutionary effects of aquaculture activities were not ignored, the total amount of waste discharged from aquatic farms, and its impact on development programmes were seldom recognised, particularly from the sustainability point of view.

Sustainability and environmental management

In the past the focus of attention in fisheries and aquaculture management has been on increasing yield by intensification of capture and culture practices, with a view to short-term economic viability. The concept of sustainability and environmental management became significant considerations as a result of discussions at the Earth Summit in Rio de Janeiro in 1992 (UNCED, 1992).

The Bruntland Commission (the World Commission on Environment and Development) in its report on Our Common Future defines sustainable development as that which meets the needs of the present without compromising the capacity of future generations to meet their own needs (WCED, 1987).To provide an operational perspective, sustainable development has been defined by FAO/Netherlands (1991) as

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

Pollutionary effects of waste discharges from aquatic farms

In order to quantify and compare the pollutionary effect of waste from aquatic farms

In order to quantify and compare the pollutionary effect of waste discharges from large marine farms in Nordic countries, the Norwegian Institute of Water Research (NIVA) recently surveyed waste discharges from salmonid cage farms in Norway and found that production of about 290 000 tonnes of salmonids in coastal cage culture in 1998 has led to a

feed-based pollution of 4255tons of P and 20 286 tons of N into the environment of produced fish (Bergheim, 2000). This annual total load of nitrogen and phosphorus is not very
high in comparison with the total load of these elements in the seawater (Hikanson et al., 1988). The load of nitrogen derived from agriculture, industries and waste water treatment in Denmark alone was estimated to be around 460 000 tons per year. The only logical reason for alarm about environmental degradation as a result of expansion and intensification is that it can cause appreciable increases in its pollutive effects. Being a new and emerging industry, its potential is greatly overrated, though social or political considerations may see an urgency in preventing its expansion.

Irrespective of how aquaculture compares with other sources of negative impacts, aquaculture development itself will be affected adversely if technologies adopted degrade the environment, as has been demonstrated in the collapse of shrimp farms or the pen culture of milkfish and tilapia in certain areas. Water quality can seldom be maintained economically in commercial farms if natural sources are polluted and the environmental integrity of the area is challenged.

Controlled use of natural resources

Polyculture is one means of developing aquaculture as a sustainable activity (Grant, 1999).
Since external feeding is not required, bivalves constitute a primary product and serve as biofilters in the integrated system. They can be managed as polyculture constituents with marine and brackishwater plants and animals that make use of the dissolved nutrients and organic matter (Negroni, 2000). No net addition of nitrogen and phosphorus to the environment as a result of external food consumption is involved. However, as in other coastal aquaculture

systems such as the pen and cage culture, considerable accumulation on the sea floor of organic matter in excreted waste from farmed bivalves could cause deterioration of water quality and unfavourable biological changes around the aquaculture installations. It is estimated that a typical oyster rack having 460 000 oysters could produce about 16 tons of faecal matter in one season (Nunes and Parsons, 1998). On the positive side, bivalves are such highly efficient biofilters that an individual mussel for example can filter 2–5 litres of water per day. Further, bivalves can retain 35–40 percent of seston ingested (Barg, 1992). In spite of constraints, polyculture remains an effective system of aquaculture production (Grant, 1999).

The prerequisite for sustainable development is the controlled use of natural resources on a renewable basis to meet food security of increasing populations and their economic growth. It is very likely that advancements in technology will accompany generational changes, but it is difficult to foresee the interdependent options available to future generations.

One can devise environmental management techniques, but it is not likely that a generation can avoid using intensive production technology to feed increasing populations which in turn will cause greater environmental perturbation. Intensive farming often gives rise to occurrence of diseases, which reduce yields and consequently the returns on investments. Growth in aquatic farming did not result in an increase of sustainability on a long-term basis,and did not take into account natural resource assessment that incorporates environmental externalities in cost-benefit analyses. Without stakeholder involvement, the public image of aquaculture in many areas became damaged and led to opposition from media, politicians, and environmentalists.

Selection of sites and farming practices

Although there are several reasons for the opposition to the steady increase in aquaculture, there is also recognition that the capture fisheries in many parts of the world have not been managed to ensure sustainability and that aquaculture is the only growth sector in fisheries.

Therefore to maintain aquatic production it is necessary to expand aquaculture.This situation has occurred at a time when social and environmental problems have become dominant issues in development. Sustainability has achieved worldwide recognition as a policy to be followed.Aquaculture, like any other human activity, has been looking at ways in which it can be promoted as a sustainable activity. In this search for the solution to the environmental and economic problems encountered, it has become quite clear that most of the problems are related to the sites where individual farms are situated, and therefore site selection has become an important part of aquaculture.

Sites have to be selected to ensure that the activities in the farm do not exceed the carrying capacity of the environment. The precautionary approach that UNCED (1987) recommended recognized that many development projects may have uncertain and potentially damaging implications for the environment that are not readily observable and should therefore sustainability, particularly those projects utilizing natural resources. Aquaculture and aquaculture-based fisheries fall into this category of natural resource-based development. In the past, research and experimentation have been guided by the objectives of obtaining increased yields by intensifying aquacultural practices. Lack of tested sustainable practices was viewed as another impediment to the emerging infant industry, without a clear idea of the dimensions of sustainability. Aquaculture had been based on the principle of short-term economic viability. When this was affected by

disease outbreaks as a result of self-pollution or external waste discharges, there was general recognition that environmental sustainability is a valid idea to be considered.
From the definitions quoted earlier, it is clear that sustainability can be interpreted and understood differently according to interest in the various aspects involved. The practical meaning of sustainable development will rarely be agreed in relation to practical development decisions. This results in specific discussions of the trade-offs between different development and conservation objectives and their associated activities (GESAMP, 2001).
The estimation of environmental capacity is basic to the selection of zones for aquaculture sites and is relevant to the allocation of appropriate areas for the promotion of aquaculture by the state. Assessment may not be as detailed as in the case of environmental perturbation.
With increasing efforts to eradicate poverty, succeeding generations may not be poor, and their needs may change in line with future economic development.
In aquaculture the main forms of wastes that are of importance in environmental management are suspended solids and dissolved nutrients, especially sources of nitrogen and phosphorus. The major sources of these wastes are accumulations of uneaten or spilled feeds and faecal matter. For example, shrimp farm waste is mainly composed of uneaten feed and faecal matter which account for 15–20 per cent and 20–25 per cent of feed given respectively (Primavera, 1994).
In tidal ponds, the inflows may contain appreciable quantities of organic matter. This, along with the nutrients and unutilized primary production resulting from fertilization, may give rise to algal blooms. The need to avoid overfertilizing

of farms through excessive application of organic or chemical fertilizers is widely recognized but over-feeding is not so apparent, especially when automatic feeding techniques are used. It has been estimated that feed losses in processed feeds may vary from 5 to 20 per cent, and over-feeding can reduce feed digestibility and increase faecal production significantly. The use of computerized feeding systems, based on automatic monitoring of the environment and food conversion ratios, are effective in minimizing feed losses.

Ackeforce and Ennel (1994) consider that the discharge of nutrients and organic material to surrounding waters is inevitable in the open cage system used in Nordic countries. When assessing the environmental impact of aquaculture the feed coefficient and the content of phosphorus in the feed are two important factors to be considered. Mass balance calculations are used to assess the discharge of polluting substances. The feed coefficient in many north European aquaculture units has been reduced from 2.3 to less than 1.3 as a result of experience in the formulation of improved feeds. The nitrogen content in the commercial feeds has been decreased from 7.8 per cent and the phosphorus content from 1.7 to <1 per cent.

As a result, for every ton of fish produced, discharges of phosphorus now are <10kg and nitrogen <53 kg (Ackeforce and Ennel, 1994).

Though imposing restrictions in feed-making at entry point through policy and regulation for reducing pollution is thus possible, regulating effluent quality (exit point) is preferred since this would give more avenues for diversifying feeds according to the availability, quality and costs of ingredients and ingenuity of the farmer

(Tacon and Forster, 2003).
The processing method adopted in commercial feeds is of importance in reducing the pollutive effects of feed-derived wastes. Extruded pellets have a slow sinking rate and higher water stability and availability. The ingredients that compose the feeds are also important from the point of view of waste production. Commercial salmon feed now has the composition of 30 per cent fat, 40 per cent protein and 13 per cent carbohydrate, with an energy content of 19.2mJ/kg (Wilson, 1994). The nitrogen content is now about 7 per cent and the fish utilizes fat instead of protein for energy, with lesser volumes of nitrogenous compounds such as ammonia being excreted.There is less excretion of phosphorus, since its content has been reduced to about 1 per cent in the diet.
Feed management includes the regulation of the size of feed according to the size of biomass and age composition and intervals of feeding according to environmental conditions. To avoid wastes and feed spillage many advanced farms, whether land-based or off-shore, hatcheries or rearing facilities, use computer programs to regulate feeding according to daily variations in the weather conditions. By the use of such adjusted feeding procedures, feed conversion efficiencies have been increased and quality of effluent discharged into waterways enhanced.
Commercial fish feeds generally use fish meal as a major component even in improved formulations (Ennel, 1995) to reduce waste

discharge. In the light of the controversial prediction that there may be a shortage of fish meal (Wickjstrom and New, 1989) and alleged overformulation (De Silva, 1999), the search for suitable substitutes has to be continued. Besides reducing fish meal as a source of proteins, manufacturers use meat meal, bone meal, blood meal, poultry meal and dried brewer's yeast to reduce fish meal in aquafeeds. Kaushik et al. (1995) reported the effects on growth, protein utilization, and potential estrogenic or antigenic effects of its partial or total replacement by soybean meal (see Chapters 4 and 7).

Environmental impacts of aquaculture are very much associated with the type of farming adopted and the species under culture.The sites where farms are located have a considerable role in determining the environmental impacts of culture operations, so it is important to bring to bear the impact assessment data that are significant to the selection of sites for farm development. GESAMP (1996a; 1996b) recommended estimating the amount of effluent from the farms discharged into neighbouring waterways and the ability of these water bodies to disperse/assimilate the wastes. The quantity of wastes from aquatic farms will vary with the intensity of farming operations, but the assimilative capacity of waste discharges will depend very much on the flushing rate of the receiving water, or regular removal of farm sediment.

Since many farms are provided with water inlets and outlets, it is considered beneficial to have sedimentation tanks associated with inlets or outlets of farms. Where regulations have been practised, one important condition to be satisfied in the design of the farm may be to reserve space for settling tanks to the extent of at least 10 per cent of the farm area.

Negroni (2000) considers constructed wetlands an attractive option for the disposal of fish farm effluents. Macrophytes can clean waste water containing potential pollutants by direct assimilation. The major removal mechanisms for nitrogen are nitrification and denitrification, mediated mainly through bacteria.

Phosphorus removal occurs as a result of adsorption. Pathogens are removed during passage of waste water through sedimentation and filtration. Some use probiotics to displace pathogens responsible for the occurrence of shrimp diseases, but Sonnenholzner and Boyd (2000) found this ineffective with commercially available probiotics.

It has been pointed out that site selection in aquatic farming has a significant role in social impacts. If not properly located aquaculture farms can affect the present livelihood of neighbouring villages. Very often large coastal aquaculture farms prevent easy access to the beaches where small-scale fishermen beach their boats and dry their nets. Farm operations may obstruct fishermen from carrying out their fishing activities. Complaints about attempts to privatise common property resources have to be avoided to prevent adverse social impacts. If proper care is not taken in farm siting as well as in the design and construction of adequately wide buffer zones and embankments, it is likely that neighbouring agriculture fields may be affected by the salinization of soils. Drinking water sources may also be affected by salinization. Where ground water has to be pumped for the reduction of salinity of farm ponds, there is a risk of land subsidence. In coastal sites the construction of farms may give rise to soil erosion and the destruction of mangroves.

Guidelines for sustainable aquaculture and transport of live aquatic animals

From the earliest time, aquaculture and aquaculture-based fisheries were founded largely on non-indigenous species in different juvenile stages, including embryos, fry and fingerlings. Scientific bodies always advised a responsible system of screening, but this was seldom practiced because of the stringent nature of the procedure and the lack of legislative support. This has resulted in the widespread occurrence of diseases and damage to the environment. Because of the improvement in transport facilities and the increase of aquaculture activities, it has become urgent to take action to prevent the unregulated transboundary movement of aquatic organisms. Transfer or movement of an aquatic animal to an area within the established or historical range of the species is permissible. The role of health management is to reduce the risk arising from the entry of the pathogen and the spread of the pathogens to a manageable level

Guidelines of principles and standards

Even though there is general agreement on the need for aquaculture and culture-based fisheries to meet the increasing demand for aquatic products, there is not such agreement on the procedures to be followed for sustainability in the intergeneric and social dimensions of aquaculture development. The absence of adequate scientific data cannot be used as a reason for
postponing or failing to take conservation and management measures (FAO, 1995). Farmers and producers have achieved considerable experience that can be used for focusing research being carried out in several institutions and pilot farms, which may lead to scientific technologies for achieving sustainability. Several national, regional and international institutions have undertaken the task of compiling and analysing the data acquired so far to prepare guidelines or codes of best practice
for future use (FAO/NACA/1995; FAO,
1995; NENT, 1995; INFOFISH 1996; NATS,
1998; D'Abramo and Hargreaves, 1997; ADB/
NACA, 1998).

The guidelines prepared by various consultations,
conferences and international organizations
set out principles and standards to ensure effective ecological sustainability. Even though it is recognized that sustainability can be achieved only by the cooperative efforts of stakeholders, governments have a major role in promoting and facilitating this through enabling legislation and ensuring its implementation.

Therefore most guidelines are addressed to sovereign state governments. The governments are required to enforce a planning mechanism for aquaculture development on the basis of the availability of resources. Zoning is undertaken on the suitability of areas, without conflict with other uses as far as possible. This may involve the balancing of benefits and detriments, including quantification of economic, environmental and social aspects. Planning of individual farms and farming in general should be based on impact assessments and formulation of mitigatory measures against adverse impacts, if any. Regular monitoring of these measures has to be promoted to minimize adverse ecological changes, and promote the rational use of resources shared by aquaculture
and other legitimate activities.

Regulation and licensing

Even though the codes of conduct are not mandatory, regular legislative measures, such as licensing of farms based on impact assessment, can assist the implementation of the guidelines, which are meant for long-term economic benefits to present and future generations. When designing and constructing farms it should be ensured that the livelihood of local communities and their access to fishing grounds are not impaired. Farms should not obstruct small-scale fishermen from carrying out their fishing activities and should add to their income by the trade in live fry and fingerlings.

Pumping of groundwater to reduce the salinity of farms should be avoided, as also should salinization of adjacent agriculture land due to seepage through embankments.

Development agencies should be made responsible for the implementation of fish health management practices, including the use of vaccines and quarantine measures for exotic animal introductions. Safe and effective use of Sustainability and environmental management of aquaculture therapeutant hormones, drugs, antibiotics and other disease control chemicals should be permitted, including the observance of appropriate withdrawal periods of drugs and the containment of residues of chemicals and other toxins.

The state agencies concerned should ensure the food safety of aquaculture products including genetically modified food organisms.

Aquaculture zones

Even when farms are designed and operated according to scientific principles, clustering of sites without due accounting of their carrying capacity can damage the environment and affect their sustainability.

Guidelines relating to coastal aquaculture and culture-based fisheries within transboundary aquatic systems emphasize the need for integrated coastal zone management. It is necessary that areas and resources important for different types of aquaculture are protected from being irreversibly allocated for other purposes. The best sectoral use for an area can perhaps be decided on the basis of the lowest pollution cost in relation to the value of the sectoral product.

For example, in coastal zones shrimp farming can be more acceptable than agriculture on the basis of income generated per defined unit of pollution (Preston et al., 2001).

To facilitate the implementation of the guidelines for achieving the sustainability of aquaculture practices it is necessary that the various governmental agencies coordinate their activities.

Regulations relating to the movement of exotic and genetically modified species can be implemented only through the willing cooperation of farmers, producers and local government officials. It has to be the responsibility of the state authorities concerned to protect the transboundary aquatic ecosystem by promoting sustainable aquaculture practices within the region, decided on the basis of consultations among the concerned state agencies. Suitable mechanisms, such as the exchange of data bases and the establishment of information networks, have to be developed to collect, share and disseminate relevant information relating to aquaculture and aquaculture-based fisheries, in order to facilitate cooperation in the planning of development at national, regional and global levels. Efforts should be made to conserve genetic diversity and maintain the integrity of aquatic systems. There are well-developed systems to minimize disease outbreaks and detrimental effects caused by escaped fish from farms and enhanced stocks. The states should consider the licensing of farming enterprises based on environmental impact assessments.

Licensing

Licenses should include the precondition of monitoring the mitigatory measures to be provided if found necessary on impact assessment

studies. These may cover water usage and waste disposal such as settling tanks, restrictions on the use of mangrove swamps for the location of
farms, and polyculture with bivalves and weeds that make productive use of particulate and dissolved
wastes (FAO/NACA, 1996). Since most of the wastes in fish culture farms are produced by feed sediments and feed spillage, feed manufacturers
should be encouraged to improve the water-stability of feeds and the feed quality by reducing proteins and increasing lipid contents, so as to decrease the emission of nitrogen and phosphorus to the farm environment.

Processing of feed by extrusion methods, though expensive, may result in the production of eco-friendly feed. Because of the need for reducing the fishmeal content of the feeds, the replacement of proteins and lipids should be promoted. In recognition of the potential of aquaculture to contribute to the world food supply, national, regional and international authorities should give high priority to the
transfer, adaptation and development of technological
innovations and capacity-building to
stimulate aquaculture practices and establish economical culture-based fisheries.