CHAPTER 40

ECOSYSTEM CONCEPTS FOR SUSTAINABLE MARICULTURE

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Introduction

Almost 50% of all seafood eaten worldwide today is farmed, compared to only 9% in 1980, primarily from the expansion of aquaculture in China and India. Increasing seafood production in an environmentally and socially responsible way will likely require the use of policy tools, such as good management practices (GMPs) and performance standards. These policy tools are commonly utilized to reduce effects associated with the use of natural resources in commercial activities like mariculture. Although mariculture operations may expand the production of seafood without additional exploitation of wild populations, they still depend upon and affect natural ecosystems and ecosystem services. GMPs and performance standards are useful for protecting the environment while increasing mariculture production.

Mariculture can have both positive and negative ecological impacts on the marine environment. For instance, culture operations and the associated gear can alter water flow, composition of the sediment, and rate of sedimentation and in some cases can disturb the benthic flora, including sea grass, which provide habitat for fish and invertebrates. However, mariculture gear increases the availability of hard substrates, thereby supporting higher densities of fish and invertebrates that associate with structured habitat, but the presence of artificial hard substrates can also promote colonization and spread of introduced species, such as non-native ones. Such a mix of beneficial and negative effects illustrates the complexity of ecosystem responses to mariculture operations.

From organism to ecosystem, there is no free lunch-every additional animal has an incremental effect arising from food extraction and waste excretion. The scope of impacts of cultured organisms is a function of the scale and location of mariculture operations, a fact that needs to be recognized and quantified. Some effects may be beneficial to the ecosystem, while others may be detrimental, depending on the scale and location of the farm.

Economic activities in marine and coastal areas, whether fisheries, aquaculture, or tourism, depend on the capacity of marine and coastal ecosystems to provide seafood for human consumption and fish for feed production, as well as coastal and marine waters suitable for recreation.

The development of modern aquaculture has been founded on social norms and rules that rely on technology, indicators of welfare, and world views that mentally alienate people from their dependence on functional ecosystems.

Since global marine fish stocks show signs of serious overharvesting, and spawning and breeding areas worldwide are increasingly degraded, it is necessary to develop concepts and management tools that take into account the support of coastal and marine ecosystems. The marine and coastal footprint of seafood production and waste assimilation, and report on estimates of regional and global appropriation of marine and coastal ecosystems is useful in ecological footprint analyses in relation to the management of mariculture for sustainability.

The capacity of marine and coastal ecosystems to sustain seafood production and consumption is seldom accounted for. Estimates of marine and coastal areas appropriated by farming for seafood production-the ecological footprint-ranges from negligible to as much as 50 000 ha/ha activity, largely depending on the methods of farming and fishing. The area for waste assimilation ranges from 2 to 275 ha/ha seafood production. The capacity of marine and coastal ecosystems to produce seafood is not included in the signals that guide economic development. Practices that make use of this capacity without degrading it have to be developed and protected from economic and social driving forces that create incentives for misuse of coastal and marine ecosystems.

Marine and coastal ecosystem support of aquaculture and fisheries

Due to current overexploitation of the world fisheries resources, aquaculture is often promoted to be the most likely source of additional seafood production. Its expansion has been given high priority, both in developed and developing countries. However, the rapidly expanding modern aquaculture technology (predominantly monocultures) has mainly used ecosystems as a medium for culturing, and has taken the necessity of a supply of resources like feed, water *etc*. and ecosystem services like waste assimilation, for granted. Intensive aquaculture is not a substitute for fisheries and on the contrary, intensive aquaculture largely depends on fisheries to harvest the seafood that is given to the cultured species in the form of pellets unless and until suitable replacement for fishmeal and fish oil are found out.

Ecological footprints and farming intensity

The dependence on external ecosystems for resource production and waste assimilation generally decreases from intensive to extensive techniques. While intensive cage farming has been increasingly dependent on external inputs and affecting the environment through releases of waste, semi-intensive farming is characterized by a more complete utilization of material and energy and a higher recycling of organic matter and nutrients within the pond system. Semi-intensive aquaculture relies both on natural food production in the ponds, and supplementary feed, usually from locally available plants or agriculture by-products. Thus, fish can obtain a major part of their nutritional requirements from local natural sources when reared at low densities in a pond.

Integrated cultures are often based on recycling or eco-cyclic production, and have the potential to be more in tune with the processes and functions of the supporting marine ecosystem.

Integrated multi-trophic aquaculture (IMTA)

IMTA refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system. Integrated marine aquaculture can cover a diverse range of co-culture/ farming practices, and even more specialized forms of integration such as mangrove planting with aquaculture, called aquasilviculture. Integrated mariculture has many benefits, among which bioremediation is one of the most relevant, and yet is not valued in its real social and economic potential for the integration benefits derived from bioremediation. Reducing risks is also an advantage and profitable aspect of farming multiple species in marine environments. A diversified product portfolio increases the resilience of the operation, for instance when facing changing prices for one of the farmed species or the accidental catastrophic destruction of a crop.

Integrated mariculture systems must be developed in order to assist sustainable expansion of the sector in coastal and marine ecosystems thus responding to the global increase for seafood demand but with a new paradigm of more efficient food production systems. Successful integrated mariculture operations must consider all relevant stakeholders into its development plan; government, industry, academia, the general public and non-governmental organizations must work together and the role of integrated mariculture within integrated coastal zone management plans must be clearly defined.

An important issue of IMTA is to adopt management practices that avoid or reduce the likelihood of disease transmission within and between aquaculture facilities or to the natural aquatic fauna. Also, careful consideration should be paid to the selection of species used in polyculture or IMTA to reduce potential stress and suffering of culture individuals. Integrated aquaculture should be looked upon as a very important tool to facilitate the growth of marine aquaculture and promote sustainable development.

IMTA for Mariculture Sustainability

The rapid development of intensive fed aquaculture of monospecies (*e.g.* finfish and shrimp) throughout the world is associated with concerns about the environmental impacts, especially where activities are highly concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently, prone to being exceeded.

One of the main environmental issues is the direct discharge of nutrient loads into coastal waters from open water systems and with the effluents from land-based systems. In its search for best management practices, the aquaculture industry should develop innovative and responsible practices that optimize its efficiency and create diversification, while ensuring the remediation of the consequences of its activities to maintain the health of coastal waters. To avoid pronounced shifts in coastal processes, conversion, not dilution, is a solution used for centuries in Asian countries. By integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed and shellfish), the wastes of one resource user become a resource (fertilizer or food) for the others. Such a balanced ecosystem approach provides nutrient bioremediation capability, mutual benefits to the co-cultured organisms, economic diversification by producing other value-added marine crops and increased profitability per cultivation unit for the aquaculture industry.

As guidelines and regulations on aquaculture effluents are forthcoming in several countries, using appropriately selected seaweeds as renewable biological nutrient scrubbers represents a cost-effective means for reaching compliance by reducing the internalization of the total environmental costs. By adopting integrated polytrophic practices, the aquaculture industry should find increasing environmental, economic, and social acceptability and become a full and sustainable partner within the development of integrated coastal management frameworks.

Good management practices (GMPs) and performance standards

GMPs represent one approach to protecting against undesirable consequences of mariculture. GMPs for farming have been prepared by industry groups, nongovernmental organizations, and governments with the common goal of sustainability. An alternative approach to voluntary or mandatory GMPs is the establishment of performance standards for mariculture. In mariculture, variability in environmental conditions makes it difficult to develop GMPs that are sufficiently flexible and adaptable to protect ecosystem integrity across a broad range of locations and conditions. Because GMPs address mariculture methods rather than monitoring actual ecosystem responses, they do not guarantee that detrimental ecosystem impacts will be controlled or that unacceptable impact will be avoided. Adoption of performance standards is likely to encourage innovation among growers. With performance standards, mariculture operations are managed adaptively to maintain key indicators within acceptable bounds, through direct monitoring of ecosystem indicators rather than tracking compliance with specific management practices.

Carrying capacity and aquaculture

Carrying capacity can be defined as the maximum population or biomass that an area will support sustainably, as set by available space, food and other potentially limiting resources but within the limits set by the capacity of the ecosystem to process biological wastes and by social tolerance for the change in environmental attributes. The concept of carrying capacity is increasingly and appropriately invoked as a quantitative guide to identify limits to stocking densities of finfish/ shellfishes in mariculture operations. Application of a carrying capacity concept to setting mariculture stocking limits requires a determination on what represents acceptable versus unacceptable impacts. Carrying capacity models can be used to optimize production of the cultured organisms; reduce the ecological impacts on the food web; or maintain societal values, such as scenic amenity or recreational opportunity. All carrying capacity approaches require models of the mariculture activity and its interactions with living and non-living components of the ecosystem.

Mariculture contrasted with capture fisheries

Many ecological effects of mariculture closely parallel the corresponding ecological effects of wild-stock harvests. Mariculture conducted on lines, racks, or cages does not require dredging and is thus less damaging to the ecosystem than wild-stock harvesting. Wild-stock harvests tend to be more frequent and more dispersed, thus causing greater damage to the ecosystem than the less frequent, more localized, and managed harvest of farmed animals. Basic economics suggests that increasing supply through mariculture will reduce seafood prices if other factors remain unchanged. Lower prices will tend to reduce economic incentives to harvest the wild population, thereby reducing fishing pressure on the wild stock. However, this effect can be masked in practice if wild-harvest fisheries remain profitable even at lower prices, if overall demand for the product increases, or if a strong niche market develops for the wild-harvest product.

Ecosystem services by mariculture

Filter-feeding bivalves have the ability to reduce water turbidity through their filtration, and they do fertilize benthic habitats through bio deposition, induce denitrification, counteract some detrimental effects of eutrophication in shallow waters, sequester carbon, provide structural habitats for other marine organisms, and stabilize habitats and shorelines. These ecosystem services of bivalves, along with recognition that oysters, clams, and scallops have been depleted dramatically below historical baselines in many estuaries, explain why bivalve mollusc restoration has become an important component of many programs for restoring impaired estuaries and some coastal waters.

Applying an ecosystem-based approach to mariculture

The ecosystem approach to aquaculture is defined as a strategic approach to development and management of the sector aiming to integrate aquaculture within the wider ecosystem such that it promotes sustainability of interlinked social-ecological systems.

An ecosystem approach to aquaculture (EAA) is not a new approach, and has been in a way practiced since the early stages of aquaculture in small-scale inland aquaculture activities particularly in Asia where poultry wastes (or other organic wastes) are commonly used as feed resources for the culture of carps and other freshwater fish. However, the EAA becomes more difficult and a real challenge in the case of intensive, industrial production but also as a result of the added effect of many small-scale aquaculture. It is not uncommon that nutrient cycling and re-utilization of wastes by other forms of aquaculture or local fisheries, is not allowed, or is discouraged.

An ecosystem approach accounts for a complete range of stakeholders, spheres of influences and other interlinked processes. In the case of aquaculture, applying an ecosystem-based approach must involve physical, ecological, social and economic systems, in the planning for community development, also taking into account stakeholders in the wider social, economic and environmental contexts of aquaculture. The first principle for an ecosystem approach, as described by the Convention on Biological Diversity (CBD), is that the objectives of management of land, water and living resources are matters of societal choice (UNEP/CBD/COP/5/23/ decision V/6, 103-106).

Key principles

The EAA can be regarded as "the" strategy to ensure aquaculture contribution to sustainable development and should be guided by three main principles which are also interlinked:

Principle 1: "Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society". It is only realistic to expect that aquaculture, being a human activity, will lead to some loss of biodiversity or affect ecosystem services to some extent. Integrated Multitrophic Aquaculture (IMTA) has been practised in Asia/China since the beginning of aquaculture, this due to their ancient concept of treating effluents and residues from farming practices as resources rather than as pollutants.

In the case of biodiversity, local declines may be acceptable (e.g. below fish cages) as long as such losses can be compensated and restored, at least at the water body scale, in order to preserve ecosystem functions and services. For example after a cage farm operation is halted it is expected that the relevant biodiversity recovers if there is enough green infrastructure, that is conservation areas or more pristine areas to provide relevant colonization and restoration. Efforts need to be made in order to permanently monitor aquaculture effects on biodiversity to make sure that such effects do not result in serious/ significant losses of ecosystem functions and services. In this respect real values of ecosystem "goods" and services should be integrated into micro and macro environmental accounting.

Principle 2: "Aquaculture should improve human well-being and equity for all relevant stakeholders". This principle seeks to ensure that aquaculture provides equal opportunities for development and that its benefits are properly shared, and that it does not result in any detriment for any groups of society, especially the poorest. It promotes both food security and safety as key components of well being. Improving human well-being should go beyond the direct contribution of aquaculture (or the attempts to use it for the purpose) to solve hunger especially in the regions where this activity is newer. In these cases its main contribution to local livelihoods comes from the increase in employment opportunities and also from the direct small business, local marketing of products.

Principle 3: "Aquaculture should be developed in the context of other sectors, policies and goals". This principle recognises the interactions between aquaculture and the larger system, in particular, the influence of the surrounding natural and social environment on aquaculture practices and results. Aquaculture does not take place in isolation and in most cases is not the only human activity – often leading to a smaller impact on water bodies than other human activities e.g. agriculture and industry. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling and better use of resources in general. Such integration has existed mostly in Asia. There are indeed many examples of integrated production systems e.g. livestock-fish farming and fish-rice production. As mentioned above, most terrestrial food producing systems have been achieved after drastically transforming landscapes, but society historically grew used to this while aquaculture is a rather new development worldwide. Therefore worldwide norms and regulations, policies *etc*. have been made well adapted to agriculture sector but not so much to aquaculture. Thus, aquaculture needs an enabling policy environment to grow in a sustainable manner and to be integrated into the agro-ecosystem and also minimizing conflict occurrence. Aquaculture can compete for freshwater and for land with agriculture but it can also use agriculture products for feeds. Plans for aquaculture development also need to be included within wider development and management schemes, e.g. integrated coastal zone management (ICZM), integrated water resources management (IWRM). Cooperation and integration of sectors in a better planed landscape particularly caring for water resources could yield greater benefits.

The connection with the fisheries sector is obvious from various perspectives e.g. production of fishmeal from fisheries (a fishery service to aquaculture), aquaculture based fisheries (where fisheries is benefiting from aquaculture) but often such connections are not formally dealt with or operational. Some of the potentially negative interactions deal with the competition for common markets, the potential damage to fisheries from the escaped farmed individuals (e.g. the case of escaped Atlantic salmon in Norway). On the other hand, terrestrial food production systems and other industrial activities can impact on aquaculture deteriorating water quality and quantity; they can also affect feed's quality and potential safety (Hites *et al*., 2004).

Some management measures to assist policy-making that ensure environmental, social and economic sustainability of the aquaculture sector In general and at all levels, policies should be generated from a participatory processes, they should be adaptive, transparent and open to the general public; they must ensure and promote people consciousness of the value of ecosystem approach. They should also reconcile temporal scales facing the fact that aquaculture growth/development and governance capabilities have been moving at two different speeds. It is also important to consider that management measures should aim to the compliance of the three EAA principles in order to ensure aquaculture contribution to sustainable development.

A precautionary approach to aquaculture production should involve developing strategies to avoid specific undesirable outcomes. Overloading of a waterbody's carrying capacity will affect the biodiversity or ecosystem services and a management plan should include estimates of the carrying capacity and mechanisms to monitor and control further loading of the system. Another example is that of culturing exotic species or genotypes, where plans should be developed or revised to incorporate precautionary elements; adaptive management practices and tools such as risk analysis and geographic information systems. Adaptive management (AM) has emerged as the "best practices" approach to ecosystem management. Adaptive management is an iterative process of taking actions, evaluating the consequences of those actions and adjusting future actions in the light of changed conditions.

Existing management models, hydrodynamic circulation/deposition models and the knowledge of local institutions, universities *etc*. can be used for the estimation of carrying capacity and use of indicators. For example, be aware of local regional particularities when importing technological packages developed in other regions as it may be necessary to develop proper management models or other tools that are more appropriate to specific local characteristics. Farm scale research should focus on developing tools to evaluate externalities of inputs and outputs, to estimate carrying capacity for individual farms, and tools and technologies for improving the feeding process and conversion ratios. It is also very important to promote permanent and proactive research on new species and strains offering enough information for the selection of the right species based on ecosystem functions and market demands, considering species requirements and ecological/nutritional efficiency.

Different kinds of incentives can be developed in isolation or in combination. *E.g.* improve the institutional framework (definition of rights and participatory processes); develop collective values (education, information, and training); create non-market economic incentives (e.g. tax mechanisms and subsidies) such as special advantageous licences (for example for integrated aquaculture, polyculture or for implemented better management, *etc.*); and establish market incentives (eco-labelling and aquaculture concessions).

Promote education and disseminate information on better practices considering ecosystem based management. At the farm scale it is important to target education and training to the stakeholders (farm owners, workers, site managers) focusing on EAA and emphasizing on management-oriented knowledge. The development of collective values and the understanding of externalities of the farming process are very relevant at this scale. The valuation and understanding of ecosystem services has to start at this scale. To develop a sustainable production in aquaculture EAA should be followed as early as possible in India also.