Ecosystem Approach to Aquaculture

V. Kripa
Central Marine Fisheries Research Institute
Cochin - 682 018, Kerala

Traditional eco-friendly farming practices

Aquaculture was practiced in several coastal areas of the world by simple methods such as collecting seed from naturally abundant areas growing them to harvestable size in coastal ponds. Simple supplementary feed using locally available natural resources wereused and the production rates were moderate. The aqua farmers were satisfied since investments were low, mass mortalities of stocked resources were rare and there was moderate profit. These traditional systems in Asia especially in China and Vietnam have been productive for more than 3000 years.These eco-friendly aquaculture practices like paddy cum fish culture have benefitted several millions of rural people in Asia and have been designated as a "Globally Important Agricultural Heritage System".

Development of modern aquaculture

With the increase in human population, the need for farmed fish increased and accordingly farming systems were modified and new systems were developed. Research on inputs required for increasing the productivity of aquaculture such as feed and seed increased and great strides were made in seed production through controlled condition in hatcheries and feed production technologies using varied raw material. Thus the traditional simple aquaculture system began to be replaced by controlled farming methods such as the semi-intensive / intensive type of farming systems where resources are stocked in high densities and farmed under controlled conditions.

Globally, Asia continues to be the leading aquaculture production region with more than 85% of production. Aquaculture provides livelihood to nearly 17–20 million aquaculture farmers in Asia and it is important that the farming systems are sustained. That is, they should continue to flourish and be productive and provide the food and financial security to the farmers. However, unplanned growth and farming without considering the ecological potential of the farming area has lead to several negative impacts both to the farm and also to the natural ecosystem.

Ecological Signals of alarm

There are clear examples of ecological damages when farms are constructedin the same location without taking into consideration the ecological carrying capacity or the potential. One example is that of Sandu Bay, a semi-enclosed bay with an area of 263 sq km whwre yellow croaker, farming was started in 1995. Qingshan region was the main cage farming area in this bay and there were about 1000 fish cages. However, the successful farming operations prompted the farmers to increase the farms each year and by 2005 the number of farms increased to 50 000. The number of farms in the Sandu bay reached 260 000. This large scale expansion lead to frequent outbreaks of low or nil oxygen levels (anoxia), frequent outbreaks of harmful algal blooms (HAB), epidemic fish diseases and mass mortality since then (Zhu and Dong 2013).

Similar problems were also observed in other farming systems and resources like the pearl oyster farms (Fu et al., 2009).

What do we learn from this? Once an ecosystem is damaged and stressed, it cannot be productive. Farmers will have only tales of woe and there will not be any profits. Livelihoods will be affected and can lead to strong social changes including emigration and change of avocation. All these teach us that ecosystem is very important and we have to consider the natural resources and the environmental factors when aquaculture is practiced.

How can aquaculture affect an ecosystem?

In a balanced natural system there is harmony between the food available (plankton, benthos etc.) and the living resources of different trophic levels. These are controlled by several environmental factors like level of nutrients, dissolve oxygen, temperature, salinity, pH, particulate organic matter, total suspended solids and so on. The benthic systems will have specific sediment texture, organic matter, levels of dissolve oxygen, hydrogen sulphide, pH and so on etc. When the ecosystem is utilized for aquaculture, the services of the living and non-living resources will be affected and this mostly depends on the type of aquaculture system like fed (eg. cage farming) or extractive (eg. bivalve farming) and open (eg. cage farming) or closed (eg. shrimp farming).

Globally, several studies have been conducted to evaluate the environment impact of farming on the ecosystem. The results of these studies give us an indication on the factor responsible for negative impact and the damage it can cause. Keeping these in mind, aqua farmers are advised to plan their farming activities in such a way that the ecosystem is not stressed and that the farming is productive.

Enhancement of Ecosystem services by aquaculture

Sometimes aquaculture promotes the ecosystem services of the region where it is farmed. Typical examples are that of bivalve culture. The farmed shellfishes remove nitrogen and other nutrients and make it available to in the food chain. They also act as a breeding place for fishes /shellfishes which favour shades and need hard substrates for attaching the eggs. They act as a fish aggregating device. They also serve to reduce the water turbidity to a certain extent.

Ecosystem Approach to Aquaculture (EAA)

In 2006, the FAO Fisheries and Aquaculture Department recognized the need to develop an ecosystem-based management approach to aquaculture to strengthen the implementation of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995). FAO proposed an ecosystem approach to aquaculture (EAA), defined as A strategy for the integration of aquaculture within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems (FAO, 2010). The strategy is guided by three key principles of which the first principle is related to environment and the ecosystem services and states that 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.

Is EAA significant?

The first principal of EAA states that the ecosystem functions and services should not be affected which means that the services provided by an ecosystem in all aspects such as resource availability and production from other activities dependingon the ecosystem (eg fisheries) should not be affected. Generally, natural ecosystems have high resilient capacities. An ecosystem is said to stable when the living resources are able to grow and reproduction thereby maintain the biodiversity of the systems. They are conditioned to the seasonal variation in environmental parameters. Even when the ecosystem is impacted by natural disasters like cyclone or flood, the ecosystem gets back to the original condition after same time. Contrary, to this, when activities like aquaculture are undertaken in an uncontrolled manner in an ecosystem, it can lead to negative impact, which in long term affect the biodiversity and sustenance. This usually happens when the impacts exceed the threshold and limits of the ecosystem.

One typical example is that of bivalve farming. Bivalves feed on the phytoplankton in the surrounding environment where they live. When bivalves are formed in this ecosystem, there is an additional requirement from the farmed bivalves for the phytoplankton available in the area. If the demand for food by biomass of the stocked bivalves in the farm is within the limit available and replenished by the ecosystem within the limited period there is no problem. In case, the demand of phytoplankton exceeds the supply/ regeneration then the food available to the farmed bivalves and the naturally occurring bivalves will be low. This can lead to low growth rates, affect gonad development and spawning and can affect the production. This will affect not only the bivalve farmers but also the bivalve fishers. This will also lead to a chain of events which can affect the nutrient level and survival of other higher trophic resources. To avoid such instances, we have to consider the carrying capacity.

What is carrying capacity?

Carrying capacity (CC) is an important concept in ecosystem based management. Earlier, while estimating the CC,only the resource which was farmed was taken into consideration and accordingly CC was defined as the maximum standing stock that may be kept within a particular ecosystem to maximise production without negatively affecting growth rate (Carver and Mallet 1990). Later considering the negative impacts aquaculture can have on the ecosystem services CC was redefined and now CC can be defined as "the amount of change that a process or variable may suffer within a particular ecosystem, without driving the structure and function of the ecosystem beyond certain acceptable limits" (Duarte et al. 2003).

In most aquaculture management programmes, the concept put forth by McKindsey *et al.* (2006) is considered. Here four different types of CC are considered i) physical ii)production iii) ecological and iv) social. These can be described as given below.

- **Physical carrying c**apacity is the total area of marine or brackish water farms that can be accommodated in the available physical space.
- **Production carrying capacity** is the stocking density of bivalves at which harvests are maximized.
- **Ecological carrying capacity** is the stocking or farm density which causes unacceptable ecological impacts.
- **Social carrying capacity** is the level of farm development that causes unacceptable social impacts.

Implementation of carrying capacity concepts

For sustainability, identification of critical limits (i.e. performance standards or thresholds) at whichthe levels of aquaculture developments can disrupt an ecosystem, thus requiring management actions should be known. These indicatorsare known as environmental quality standards (EQSs) and are used by planners. The

Association of Southeast Asian Nations has also started the process of standardizing water quality standards within the Southeast Asian region. In many countries, an EIA is essential as part of the licensing process for farms over a threshold size. In some regions if the farmer plans to expand an existing site beyond the approved license size then also EIA is required.

The EIA may be defined as “The process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made” (FAO, 2009). The EIA most often provides the framework for the implementation of environmental carrying capacity criteria, although it can also include social and economic impacts.

In Asia, aquaculture farm size is usually small and the EIA may not be worth monitoring individually. However, when many such farms exists in an estuary, there is a need to evaluate the overall impact on the ecosystem which is called Strategic Environmental Assessment (SEIA). This is to ensure that the sum of the small farms will not exceed the ecological carrying capacity. However, such evaluations are rarely done.

For large farms sharing a common water body, like that of shrimp farming in coastal zones. the combined effects of farms on the receiving water body (e.g. a mangrove estuary) is normally not assessed or monitored. However, the combined farm nutrient loads can exceedthe ecological carrying capacity. In such situations cluster management is advised.

Cluster management in simple terms can be defined as collective planning, decision-making and implementation of crop activities by a group of farmers in a cluster (defined geographical area for example sharing common water source) through a participatory approach in order to address the common risk factors and accomplish a common goal (Ross et al., 2013).

Environmental impacts of different farming systems

Usually coastal aquaculture farms are located in estuaries, where tidal flushing is significant and can play a critical role in determining the carrying capacity and lowering the impact on the ecosystem. A well-flushed estuary or bay can make aquaculture more sustainable, or have a larger carrying capacity, than poorly flushed basins.

Mussels, oysters, scallops, pearl oysters and seaweeds are cultured using racks, rafts or longlines. These farming practices are considered as environment friendly due to their nutrient assimilating capacity and there is practically no feed input required. However, the bivalves can cause localized bio-deposition of pseudofaeces. Since these are concentrates of phytoplankton, they can increase the soil productivity. Though mussels or oysters act as a bio-filter, organic pollution from large-scale mussel or oyster culture in form of pseudofaeces cannot be neglected.

A brief summary of the impacts of extractive type of farming such as bivalve farming on the ecosystem are given below.

- Reduction in phytoplankton / seston.
- Increased water clarity leading growth of sea grasses.
- Increased abundance of cyanobacteria under bivalve farms.
- Higher organic nitrogen, total nitrogen, chlorophyll, phaeopigments in the surface sediments.

- Increased sedimentation.
- Alteration of sediment texture /sediment geochemistry.
- Altered soil Eh.
- Lower species diversity in sediment communities.
- Reduced macrofaunal biomass.
- Modification of current patterns.
- Higher abundance of benthic predator communities.
- Higher sulphide levels.
- Low oxygen levels.
- Altered sediment phosphate fluxes.
- Deposition of dead bivalve shells.

Finfishes and shrimps have to be provided supplementary feed when they are stocked in cages or in earthen ponds. Most of the farms are located in near shore coastal waters and the impacts are localized. In these systems the excess feed and the wastes from the farm can cause ecological damages. Some of the significant damages /changes due to fed type of farming is given below

- Increased nutrient levels in water due to supplementary feed.
- Changes in phytoplankton community due to varied nutrient levels.
- Increased nutrient levels in sediment.
- Altered soil redox potential.
- Anoxic conditions in the sediment beneath the cage.
- Increased bacterial growth in the sediment.
- Different sediment texture.
- Changes in benthic community structure.
- Altered microbial population.
- Escape of farmed species and change in natural diversity.
- Increased occurrence of disease.
- High BOD levels.

Need for sustainability in ecosystems

Though Asia is the largest aquaculture industry in the world, there are only very few large-scale aquaculture corporations in this region. Most of the production comes from millions of small-scale farms owned by individual farmers. This makes ecosystem management and coordination difficult. Since 1990 there has been rapid growth of aquaculture production supported by technical progress such as technology for manufacture of commercial feeds,seed and aquaculture support systems and this has significantly improved the living standards of most aquaculture farmers. This has also caused the immoderate expansion of farming scale (Dong et al., 1998) and over carrying capacity farming has become a common issue in many coastal and inland systems.

Since most aquaculture farms are situated in the rural and suburban area, which are not economically developed as other regions, local government or policy implementers find it difficult to strictly enforce the laws which curtail farming even if it is for the cause of sustainability. Hence rules related to carrying capacity (eg number of farms per unit area) and water quality management (eg. discharge of effluent water from shrimp ponds) can only be partly enforced.

For different aquaculture systems, the best management practices which support sustained production from the farming system and also support ecosystem services of the adjoining water resources are varied. Farmers and planners are advised to adhere to the EIA procedures and restrict activities which will stress the ecosystem.

Eco labeling and certification in aquaculture

Globally sea food consumers became concerned about the quality of the farmed product during the 1990'swhich is marketed and also about the damage to the ecosystem done through irresponsible farming. This led to the development of concepts such as eco-labeling and organic farming.

Aquaculture certification is a potential market-based tool for mitigating negative environmental impacts and enhancing societal and consumer benefits (FAO, 2012). The Article 9.1.5 of FAO Code of Conduct for Responsible Fisheries (FAO, 1995) prescribes that "States should establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water extraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities".

At present there are at least 30 certification schemes relevant to aquaculture and these includes chemes promoted by retailers, aquaculture industry, governments and NGOs; organic certification schemes; fair trade certification schemes and other schemes. The number of certification and ecolabeling schemes for aquaculture products has significantly increased over the years.

Organic certification addresses the processes involved in production rather than the qualities of the product itself. Organic farming is based on holistic production management systems which promote and enhance agro-ecosystem health, including biodiversity, biological cycles and biological activity. In general, organically farmed fish which is farmed without using antibiotics and pesticides is perceived to be more "natural" and therefore healthier, or even tastier. Because of these new concepts which promote eco-friendly aquaculture, there is a tendency to prevent environment degradation and promote sustainability.

References

Cao L, Wang W, Yang Y, Yang C,Yuan Z, Xiong S and Diana J. 2007. Environmental Impact of Aquaculture and Counter measures to Aquaculture Pollution in China. *Env Sci Pollut Res* 14 (7) 452–462.

Carver C.E. A and Mallet A. L.,1990. Estimating carrying capacity of a coastal inlet for mussel culture *Aquaculture*, 88: 39-53.

Dankers N and Zuidema, D.R., 1995. The role of the mussel (Mytilusedulis L.) and mussel culture in the Dutch Wadden Sea. *Estuaries*, 18: 71-80.

Dong, S., Pan, K. & Li, D., 1998. On the Carrying Capacity of Mariculture. *Journal of Ocean University of Qingdao*, 28 (2): 245–250.

Duarte P Hawkins A Meneses R Fang J Zhu M 2003 Mathematical modelling to access the carrying capacity for multi-species culture within coastal waters. *Ecol. Model.,* 168: 109-143.

Fu, S., Deng, C., Liang, F., Tong, Y. & Sun, Y., 2009. Study of Sustainable Development of South-Pearl Industry. *Journal of Guangdong Ocean University*. 29 (5): 1–5.FAO, 1995.

FAO. 2010. *Aquaculture development. 4. Ecosystem approach to aquaculture.* FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 4. Rome. 53 pp. (also available at www.fao.org /docrep /013 /i1750e / i1750e00.htm). FAO, 2012.

McKindsey, C.W., Thetmeyer, H., Landry, T. & Silvert, W., 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. *Aquaculture*, 261: 451–462. Soto *et al*, 2008.

Nunes, A.J.P. & Parsons, G.J. 1998. Dynamics of tropical coastal aquaculture systems and the consequences to waste production, *World Aquaculture*, 29 (2): 27–37.

Ross, L.G., Telfer, T.C., Falconer, L., Soto, D. and Aguilar-Manjarrez, J., eds. 2013. *Site selection and carrying capacities for inland and coastal aquaculture.* FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Zhu, C. and Dong, S., 2013. Aquaculture site selection and carrying capacity management in the People's Republic of China. *In* L.G. Ross, T.C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds. *Site selection and carrying capacities for inland and coastal aquaculture,* pp. 219–230. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland.

FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO, 282 pp.