Assessing and Predicting the Environmental Impact of Mariculture

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Introduction

Mariculture involves the farming and yield of fish, shellfish as well as other aquatic species including seaweeds, where in the medium of growth is seawater. The environment play crucial role in any mariculture activity. Prior to the start of any mariculture programme the environment assessment is absolutely essential for its successful launching, maintenance and harvest. This pre evaluation of environmental suitability is one of the most important factors, determining the type of mariculture fitting to the location. Appraisal of the environment at regular intervals, during the process of mariculture also is equally important for the continued healthy existence of the resources and also for ecological sustainability. The environmental impact assessment(EIA) of any undertaking including mariculture is a process of appraising the probable ecological impacts of the proposed endeavor, taking also into account the interconnected socio-economic, cultural and human-health impacts, both beneficial and adverse.

The knowledge and experience achieved as well as the results of the environmental investigations before, during and after the activity form the basis for the prediction of impacts. The need for exact predictions might not effectivelybe attained during this process, because of uncertainties in the data and if there is a lack of enough baseline data. Rather than making direct predictions, which might not be applicable in a complex natural environment, it is important that the predictions sketch out different scenarios, presenting the underlying assumptions clearly. Further, the impacts should be evaluated and environment management plans (EMP) should be prepared. An EMP is a site-specific plan developed to ensure that all necessary measures are identified and implemented in order to protect the environment and comply with environmental legislation. While this supports the environment, it should also be supportive to the optimum production of the resources.

Once, a mariculture venture is planned, the various steps in the environmental assessment are to be initiated. These steps start with site selection. The site selection determines the water quality to a great extent. Selection of particular site for mariculture is of foremost importance since it greatly influences economic feasibility of the plan.

Site selection and carrying capacity estimation

The site selection criteria are to be followed for initiating a mariculture program. The site selection and water quality criteria for selected mariculture resources (marine fish, shrimp, bivalves and seaweeds) in India were narrated by Prema (2013). Loka *et al*., (2012a) described the site selection criteria specifically for marine cage culture in India. The water quality should be in the preferred range in terms of selected parameters of concern for aquatic life in the marine sector. The importance of water quality for marine cage culture was detailed by Prema (2009). The individual environmental parameters selected as key indicators in the assessment criteria have their own roles singly as well as in combination.

The concept of environmental assessment should be elevated to an ecological approach to aquaculture (EAA) as suggested by the Fisheries and Aquaculture Department of the Food and Agriculture Organization (FAO) of the United Nations(Soto *et al*., 2008). Carrying capacity is an important concept for ecosystem-based management which facilitates defining the upper limits of production and ecological limits, and the social acceptability of the venture without causing any unacceptable changeto both natural ecosystem and social functions and structures (Byron and Costa-Pierce, 2010). Inglis *et al*. (2002) and Mc Kindsey *et al*. (2006) defined four different types of carrying capacities *viz*. physical, production, ecological and social.

- The **physical carrying capacity** is the potential of an area/site to sustain coastal aquaculture in that it has the appropriate physical characteristics (including minimalinfrastructure and access). This is the primary selection criterion for an aquacultureactivity, for site selection and aquaculture zoning.
- The **production carrying capacity** is the maximum yield that can be produced inthe selected water body. This estimates maximum aquaculture production given thesource of food and is typically considered at the farm level but should go beyondthis. It is relevant in choosing the most congenial resource / species for the culture.
- The **ecological carrying capacity c**an be described as 'the population or biomassof a species that a specific habitat can permanently sustain without damaging theecosystem from which it depends.' It is the magnitude of mariculture productionthat can be supported by the environment.
- The **social carrying capacity** can be defined as the amount/type of aquaculture (total production, number and density of farms, species and systems) that a socialsystem can take without incurring in significant negative social changes.

These four types of carrying capacity must be considered in the final decision. The selected area or site should be that where these four overlap. Although these accepted definitions were originally described for bivalve aquaculture, they have also been applied to finfish cage culture (Gacek and Legoviæ, 2010).

The information needed for site selection and estimation of carrying capacity is varied and will usually consist of data describing the physical, biological, economic, social and infrastructural aspects. These data can come from a variety of sources, ranging from primary data from the field or satellite imagery to all forms of secondary data, including paper maps, photographs and textual databases.

An example of some data requirements for carrying capacity estimation in different farming systems.

(The lists of parameters are indicative rather than exhaustive)

Farming system	Physical carrying capacity	Production carrying capacity	Ecological carrying capacity	Social carrying capacity
System 1: Coastal marinecages	Wind, Waves, Currents Depth, Temperature, Salinity, Infrastructure etc.	Temperature Salinity Diet type Feed regime Investment costs Markets etc.	Critical habitats Biodiversity ingeneral impact etc.	Eutrophication indicators EIA data Visual Sea and coastal access rights Access to capital Beneficiaries Workforceetc.
System 2: Ponds (coastal)	Water quantity, Water quality, Slope, Soils Rainfall Evaporation Infrastructure, etc.	Temperature, Diet type, Feed regime, Infrastructure, Investment, costs Markets etc.	Critical habitats, Biodiversity, Eutrophication indicators Visual impact, EIA data in General etc.	Land ownership, Water andriparian rights Access to capital Work force Beneficiaries etc.
System 3: Bivalve culture	Wind Waves Currents Chorophyll and productivity Depth, Temperature Salinity, etc.	Temperature Salinity Chlorophyll, and productivity, Investment, costs Markets etc.	Critical habitats, Biodiversity, Bottom anoxia indicators Visual impact EIA data in General etc.	Sea rights Access to capital Workforce Beneficiaries etc.
System 4: Seaweed culture	Wind Waves Currents Nutrient content, Depth Temperature Salinity, etc	Temperature, Salinity Nutrients, availability, Investment, costs Markets, etc.	Critical habitats Biodiversity Visual impact EIA data in General etc.	Sea rights Access to capital Workforce Beneficiaries etc.

In the case of shrimp farming in India, Central Institute of Brackishwater Aquaculture has carried out research on carrying capacity. The institute has developed decision support software in visual basic to estimate the maximum allowable farming area for a particular creek or drainage canal (Muralidhar *et al*., 2008). This software helps to determine a reliable estimation of impact of shrimp farming and other land use impact in a region under various scenarios of increased development. Further water quality data generated during this research would serves as a baseline data to monitor long term trends of quality of water bodies (Vijayan *et al*., 2014).

Environmental Impact Assessment (EIA)

EIA is commonly focused on high value, intensive farming, and particularly shrimp and marine cage farming Asia. In India, The Guidelines for Sustainable Development and Management of Brackish Water Aquaculture (1995) recommend to carry out a site selection process, which should include proper environmental impact assessment (FAO, 2009). They state that all aquaculture units above 40 ha should be subject to an EIA. State Pollution Control Boards should ensure that such an EIA be carried out by the aquaculture units. Shrimp culture units of 40 ha or more should also incorporate an Environmental Monitoring Plan and an Environmental Management Plan, which covers the following potential impacts: local watercourses, groundwater, drinking water sources, agricultural activity, soil and salinisation, waste watertreatment and green belt development. Smaller farms between 10 ha and 40 ha must also provide information on these items.

The Water (Prevention and Control of Pollution) Act (1974, as amended) provides for the prevention and control of water pollution, for the maintenance or restoration of the wholesomeness of water, and for the establishment of (central and state) Pollution Control Boards. The Act defines "trade effluent" for these purposes as "any liquid, gaseous or solid substance which is discharged from any premises used for carrying on any industrial operation or any treatment or disposal operation other than domestic sewage treatment".

Hence, an aquaculture farmer requires an authorization from the Pollution Control Board to set up a treatment and disposal system that is likely to discharge sewage or trade effluent into waters or onto the land.

The Coastal Aquaculture Authority of India issues Guidelines on the need for Effluent Treatment System (ETS) in shrimp farms. The low dissolved oxygen, higher organic matter; increased sedimentation load of discharged water from farms will affect the assimilation capacity of the environment and will have potential impact in the ecosystem. Such impacts depend on the quantum of waste water outflow. Hence the Marine Products Exports Development Authority (MPEDA) guidelines for sustainable culture advocates the shrimp culture units with an area of above 5 ha to have ETS facility by demarcating at least 10% of the area and have facilities for settlement, treatment and discharge as per the prescribed standards. They further advise to let the bottom sediment to dry between harvest rather than removing sediment accumulations from the pond bottom. The Guidelines also refer to the need for a common ETS for clusters of shrimp farms, where each farm is less than 5 ha in size.

The Indian guidelines on effluent discharge from coastal aquaculture farms are as follows.

Guidelines/standards for wastewater from coastal aquaculture farms in India

Parameters	Final discharge point	
	Coastal marine waters	Creeks/estuaries
pH	6.0–8.5	6.0–8.5
Suspended solids (mg/l)	100	100
Dissolved oxygen (mg/l)	Not less than 3.0	Not less than 3.0
Free ammonia (as NH^3-N) mg/l	1.0	0.5
Biochemical oxygen demand – BOD (mg/l)	50	20
Chemical oxygen demand – COD (mg/l)	100	75
Dissolved phosphate (as P) (mg/l)	<0.4	<0.2
Total nitrogen (as N) (mg/l)	2.0	2.0

An EIA consists of three stages: (i) screening, to define in what context the EIA is needed; (ii) scoping, to define what risks should be assessed and in what terms; and (iii) a written report andconsultation phase to produce an environmental impact statement which should include anenvironmental monitoring strategy to ensure the assessment of risk has been effective (Telfer and Beveridge, 2001).

Environmental assessment is an important part in environmental management of mariculture, and is an integral part of an EIA. For EIA in marine cage culture, a baseline survey prior to the start of the culture as well monitoring surveys during the culture are essential for the environment management. The Central Marine Fisheries Research Institute (CMFRI) has given the protocol for the environmental management of sea cage farms in India (Loka*et al*., 2012b).

Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment (World Bank, 2008) offers a comprehensive approach to identifying likely sectoral impacts, and establishing environmental objectives, quality standards, limits and so on for the industry. It is also a good basis for aquaculture developmentand management plans or integrated coastal zone management (ICZM) plans. The Republic of India had conducted environmental assessment in the shrimp-farming sector (White *et al.,* 2013).

Environmental impacts in mariculture

Observations on water and sediment quality on marine cage culture in India was reported by Prema *et al*., (2010), Philipose *et al*., (2012) and Varghese *et al*., (2015). In the shrimp farming sector in India, EIA had been conducted by Paulraj *et al*., (1997), Muralidhar and Gupta (2007), Jugunu and Kripa (2008). Muralidhar and Gupta (2009) brought out technologies for management of soil and water environment for shrimp culture. The EIA for bivalve mariculture in India was carried out by several studies from CMFRI (Ramalinga and Kripa, 2006, 2007, Kripa, 2011, Prema *et al*., 2012, Viji *et al*., 2014a, 2014b).The impact of environment on sea weed farming in India was well studied by CMFRI (Kaliaperumal, 1989, 1990, Kaliaperumal *et al*., 1990, 1993, 2003, Radhakrishnan, 2001, Seema and Jayasankar, 2005 and Zacharia *et al*., 2015).

De Silva and Soto (2009) narrated the impacts of climate change in mariculture. Due to climate change, sea temperature rise in tropical and subtropical regions would result in increased rate ofgrowth and overall production in aquaculture. The predicted temperature riseitself will bewithin the optimal ranges for most species cultured in such waters (marine, brackishand/or freshwater) and therefore global warming could impact positively on the bulk ofaquaculture production, provided the feed inputs required for compensating the enhanced metabolism are met and that other associated factors, such as disease, do not become more detrimental.

Climate change is predicted to decrease the pH of seawater globally (Hughes *et al.*, 2003; IPCC,2007). Apart from its impact on coral formation, there is the possibility that decreased pH could impede calcareous shell formation, particularly in molluscs, an effect perhaps can be aggravated by increased water temperature and thereby to have an impact onmollusc culture. This has received little attention and warrants urgent research. Currently, mollusc culture accounts for nearly 25 percent of all aquacultureand therefore any negative impacts on shell formation could significantly impact on total aquaculture production. There ispractically no information on the potential impact of increased water temperature on the physiology of the most relevant aquaculture bivalves. But, if coastal plankton productivity is enhanced by higher temperatures and if nutrients areavailable, there may be a positive effect on the farming of filter feeders. However, increased temperatures associated with eutrophication and harmful algal blooms (Peperzak, 2003) could augment the occurrence of toxic tides and subsequently impact production, and also increase the possibilities of human health risks through the consumption of molluscs cultured in such areas. More research is needed toprovide better forecasts of expected net effects. In India, the CMFRI has attempted to study the effects of lower pH in estuarine water on meroplanktonic oyster larval settlement. Experiments were conducted to evaluate the effects of extremes of temperature (20 to 35°C) and pH (6.5 to 8.5) on metamorphosis and survival of oyster larvae. In pH 6.5 there was 100% mortality and complete dissolution of dead shells in 24 h. Survival was highest (81%) in the control temperature of 27°C and less than 50% in 25 and 20 °C (Kripa *et al*., 2015).

The frequency of extreme weather events such as typhoons, hurricanes and unusual floods has increased dramatically over the last five decades due to climate change. Climate change in some regions of the world is likely to bring about severe weather(storms), water quality changes (e.g. from plankton blooms) and possibly increased pollutants and other damaging run off from land based sources caused by flooding, impacting on coastal areas. Such weather conditions will increase the vulnerability ofsea based aquaculture, particularly cage aquaculture, the predominant form of marine aquaculture of finfish and seaweed farming in coastal bays. There is an increased vulnerability of near-shore land based coastal aquaculture, of all forms, to severe weather, erosion and storm surges, leading to structural damage, escapes and loss of livelihoods of aquaculture farmers. Vulnerability assessments have been made by CIBA on shrimp aquaculture and found it as moderately vulnerable to climate change highly vulnerable to extreme events in Nagapattinam District, Tamil Nadu.

Prediction, prevention, adaptationand mitigation of environmental impacts

Adequate site selection and aquaculture zoning can be important adaptation measures to environmental impact. When selecting sites it is very important to determine likely threats through risk assessment analysis. When selecting the best locations forfarms, particularly in coastal and more exposed areas, weather related risksmust be considered. For example, coastal shrimp farms may need levies or otherprotective structures. Fish cages have to be securely fastened to the bottom or a holding structure. Water warming and related low oxygen, potential increase in eutrophication, etc. can be avoided or minimized indeeper sites with better circulation. The likelihood of disease spread can be minimized by increasing the minimum distance between farms for aquaculture clusters or zones. Implementing proper risk communicationis also very important. In this regard, weather information systems play an important role.

For mariculture, prevention systems should be formulated by predictive modeling based on critical and effective monitoring of water bodies and aquatic organisms. A very important adaptation measure at local level is the implementation of effective integrated monitoring systems. Such monitoring systems should provide adequate information on physical and chemical conditions of aquatic environments, early detection of diseases and presence of pest species, including harmful algal blooms.

Frequently, rural farmers may not have the conditions and facilities toimplement such monitoring by themselves. However, some very simple measurements can be implemented such as water temperature and Secchi disk readings etc can also be made at local level which can be used for early detection of algal blooms. Local authorities can assist inimplementing integrated monitoring systems with accompanying risk communication strategies and early warning systems to prepare and warn stakeholders (De Silva and Soto (2009).

Better management practices and systems to mitigate environmental impacts in mariculture in India were identified by Modayil *et al*. (2006). The first attempt in India on experimentation of spatial planning and aquaculture zoning is from CMFRI (Dineshbabu *et al*., 2015). This study provides GIS maps which will help in deciding suitable mariculture activities in specific water bodies using eco friendly methods. Geospatial delineation of potential cage culture sites in Mandapam and Veravel regions of the Indian coast was validated in CMFRI (Mini *et al*., 2015).

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