Mariculture and Biodiversity

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Introduction

Aquaculture experienced a drastic increase throughout the world with a range species from giant clam, mussels, oysters, carps, salmon, grouper, milkfish, catfish, pompano, and tuna cultured in diverse environments. Diversity observed from filter feeders, herbivore to highly carnivorous groups. Fish culture habitats also showed the diversity from estuary, lakes, mangroves, coastline, inshore to offshore areas. Two major subsectors emerged in the aquaculture sector are the family and co-operative farms mainly follow the extensive and semi-intensive practices, whereas the commercial farms follow the intensive and semi-intensive practices to produce high valued products for the global market. The aquaculture production can reduce the pressure on the capture production and can lower the investment in the fishing fleets and effort. Major farmed fish are common carp, tilapia, milkfish, cod, haddock and pollock. Mariculture is the cultivation of marine organisms in their natural habitats, usually for commercial purposes. It is the culture of organisms, both plants and animals in both the sea and inland brackish water areas. Mariculture worldwide is growing and according toFAO statistics, it showed an increase from 9 million tonnes in 1990 to more than 24.7 million tonnes in 2012. Some of the species shown potential for future growth but may be sensitive aquaculture efforts are *Acipencer* spp., *Anguilla* spp., *Epinephelus* spp., *Lates* spp., *Lutjanus* spp., *Oreochromis* spp., *Thunnus* spp., and *Ulva* spp. (CBD, 2004).

Mariculture is dominated by seaweed (Japanese Kelp) and molluscs (Pacific cupped oyster) and high valued finfish salmon. Also, there are small scale cultures of Sea horse, giant clam, microalgae, rotifers and brine shrimp. The species like milkfish, etrpolus, and mullets are cultured in brackish water. At the same time the pressure on the aquatic resources and wild fish stock is showing an increasing trend as the human population grows. The Global marine catch was about 14 million tonnes (1950), which increased to65 MMT in 2012 (FAO, 2014). It is also noted that the total catch was more or less stable around 70-65 MMT overt the last 25 years and gives the indication that there may not be further increase from the capture section. Mariculture offers good quality food and relatively more efficient thanseveral other food production systems. It is recognized that all forms of mariculture disturb the biodiversity at species, genetic and ecosystem level and will result in adverse impact. The main effects include habitat degradation, decline of wild populations, introduction of non-indigenous species, biological pollution, genetic impacts of target species and social effects like human health issues, loss of employment income of traditional fishermen. There are severalopenapproaches for circumventing the adverse effects of mariculture on biodiversity. They include the effective site selection, proper environmental assessment, proper feeding protocol, better effluent and waste control measures, better genetic resource management, setting up of hatcheries for seed collection, reducing the collection of wild seed and enhancing positive effect of mariculture to reduce the pressure on capture fisheries.

Effect of Mariculture on marine and coastal biodiversity

All forms of mariculture affect biodiversity at genetic, species and ecosystem levels, which results in the supply of ecosystem goods and services. Mariculture can change, destroyhabitat, disrupt trophic structures, spread diseases and reduce the genetic capability. The by-products of the mariculture systems like particulate organic matter, nitrogen, phosphorus, remains of antibiotics, pesticides, and hormones move into the water column. The genetic effects of mariculture are wide-ranging and highly important for biodiversity. The major effects of mariculture on marine and coastal biodiversity are summarized below.

I. Ecological effects of Mariculture

1. Effluent discharge

Mariculture activities release untreated nutrients, chemicals, feed materials, antibiotics and pharmaceuticals into marine ecosystem. This will lead to degenerated water quality in the shallow water bodies and high concentrated production areas. Nutrient loading from the culture systems will affect the biogeochemistry of the habitatsmaking it toxic to the fish and shellfish. The farmed Salmon discharged an average of 48.2 kg of nutrient nitrogen into the surrounding environment per ton of production, whereas 72.3 kg N per ton of farmed cod and 86.9 kg of N per ton of farmed turbot (Ervik *et al.*, 1997). Davies and Slaski (2003) has shown that effluent from Halibut rose in marine environments tend to have high impact as the sea cages need to be wide, shallow and in sheltered areas for optimal growth. It is estimated that waste production from farmed Halibut indicate and average loss of 66 kg N per ton of fish output.

2. Habitat modification

Large areas of mangrove and coastal areas have been converted to shrimp and fish ponds. This conversion results in the loss of ecosystem services provided by the mangroves such as nursery habitat, coastal protection, flood control, sediment trapping and water treatment (Naylor *et al.*, 2000). The loss of mangrove will affect the catch of the mangrove dependent fish species. As mangroves are closely related to the Coral reefs and sea grass beds, the change in the mangrove area will havea deleterious effect on the coral and sea grass ecosystem (Ogden, 1988).Culturing of milkfish and shrimp often involves changing mangroves and salt swamps, the ecosystem that offers many key services such as erosion control, flood control, trapping of sediments and dispensation of wastes. As the culturing intensifies natural habitats will be destroyed and can in turn result in biodiversity imbalance.

3. Use of wild seed to stock mariculture

The use of wild collected seeds for the mariculture operations in extensive, pond and cage culture activities will have consequences in the wild fisheries. Wild collected seeds are used in the milkfish culture in the Philippines and Indonesia, tuna in South Australia, shrimp in Asia and Latin America, eels in Europe and Japan (Naylor *et al.*, 2000). The fry collection results in the loss of other frys collected along with the target group and it may be some times a higher magnitude than the targeted group. The fry removed from the wild will ultimately have an impact on the wild production of the species.

4. Increased predation on wild fish and other organisms

Aquaculture in general can have incidental predation effects on other non-target organisms. A variety of piscivorous birds like terns, cormorants, pelicans, gulls, egrets, heron, and kingfisherare commonly aggregate around the culture areas.

5. Biological Pollution

The mariculture affects the wild and farmed fish through biological pollution. Escape or the accidental release of fishes into the wild from aquaculture farms,has an adverse impact on native species and ecosystem, it paves wayto a major environmental apprehension. Introduction of exotic species and the escape of genetically modified fish samples which are used for aquaculture purposes or laboratory testing result in competition and predation of wild fish varieties. Hilborn *et al.* (2003) reviewed that the introduction of exotic species as a form of biological pollution which affecting the native fish species mainly of coastal ecosystem. As a result of the introduction many indigenous varieties of fishes have been replaced by exotic varieties, and with increasing demand and world trade the frequency of exotic introduction is said to increase exponentially (Cohen *et al.,* 1998; Carlton *et al.*, 1996). The Atlantic salmon the dominant Salmon species farmed, frequently escape from farms. It was reported that about 40% of the Atlantic Salmon caught by fishermen in areas of the North Atlantic are of farmed origin (Hansen *et al.,* 1993). Farm escaped fishes may hybridize with wild and alter the genetic make-up of the wild populations which results in the decline of many locally endangered species.

II. Genetic Impacts of Mariculture

1. Genetically Modified Organisms (GMO's)

The concept of Genetically Modified Organisms is a controversial topic when it is associated with food products. The basis for developing GMO's is essential to increase the productivity, yield, resistance to parasites and diseases, enhanced nutritional quality and flavor. When compared with other higher animals, fish transgenics offers certain advantages such as large no. of eggs are laid and at the same time fertilization and embryonic development takes place outside the mother (in most species), which make them less susceptible to human pathogens and the fact that aquaculture is rapidly expanding adds on to the cause. First transgenic fish was developed in 1984, since that time more than 30 species of fishes have been genetically modified (NRC, 2002).

In general, there are two opposing views about the GMOs.

a. Precautionary: Transgenic technologies arehavingunidentifiedhazards that need to be cautiouslywatched and controlled to guarantee the protection of both the environment and human well-being.

b. Genetic engineering is a little challenging from other technologies involving genetic upgrading or domestication, and GMOs as extremely domesticated and therefore doubtful to survive in the wild if they escape, the procedure therefore needs little extra testing or oversight.

2. Transgenic Fish

Transgenic fish are those that carry or transmit copies of the recombinant DNA sequence produced *in vitro* using rDNA technology. The recombinant DNA Sequence which is introduced into the fish mainly consists of three regions; promoters or signaling region, coding region or the code for the target protein and the terminator region or stop codon. The construct is introduced into the fish at its early embryonic stage or into fertilized egg using microinjection techniques. The chance for successful incorporation of the microinjected rDNA into the fish genome is 1 out of 100. The incorporated rDNA sequence will be subsequently passed onto its progeny. The growth hormone gene has been the most extensively used target gene for transgenesis, because of its high productivity in short time with less spending on feed cost. More than 14 species of fish have been genetically engineered for enhanced growth (Van Eenennamet *al.*, 2006). These fishes are said to have higher food conversion efficiency, which results in less feed wastage and minimize effluent discharge from fish farms (Cook *et al.,* 2000).

Many varieties of fishes which are involved in the ornamental fish trade are developed into transgenic forms, which emits a glowing aura that the native breeds do not have. Zebra fish (*Danio rerio*) was the first fish species to be genetically modified with fluorescent abilities later Black tetra (*Gymnocorym busternetzi*) and Tiger barb (*Puntius tetrazona*) varieties were also modified. Another type of GMO involved in the aquarium trade is the Genetically Improved Farmed Tilapia (GIFT, *Oreochromis niloticus*), which has been labeled as the 'Frankenstein fish'. This GMO has been engineered to survive in a wider range of environmental conditions and temperatures that non-GMO individuals would be incapable of surviving in. Although none of the GMO's were approved to be used for food purpose globally, until a company named Aqua bounty got approval from FDA recently for its Aqua bounty Atlantic Salmon. Different types of transgenes used in the aquaculture are summarized in the Table 1.

Table 1.Details of transgenes and targeted phenotypes in different species of fishes.

Phenotype targeted	Fishes	Transgene
Growth	Atlantic salmon Tilapia Rainbow trout Coho salmon Chinook salmon RohuLoach	Growth hormone
Freeze tolerance	Atlantic salmon	Antifreeze protein
Disease resistance	CatfishCarpMedaka	CercopinLactoferrinCecropin
Carbohydrate metabolism	Rainbow troutRainbow trout	Glucose transporterHexokinase
Reproduction	Rainbow trout	Antisense GnRH
Lipid metabolism	Zebrafish	D6- desaturase
Phosphorus metabolism	Zebrafish	Phytase
Vitamin C metabolism	Rainbow trout	L-gulono-gamma-lacotne-oxidase

Source: Devlin R. H., Sundstrom L F. Muir W M. 2006. Interface of biotechnology and ecology for environmental risk assessment of transgenic fish. p. 89-97.

In general the genetic engineering is a complex technology executed on complex biological systems; results will produce complications. Over and over again manipulated and accidental consequences that fuel the excitements of anxiety and public expose and defend precautionary approaches to transgenic (Helfman, 2007).

3. Risk factors of Transgenic Fish and environmental impact

The main risk associated with transgenic fish is its release or escape. Concern range from interbreeding with native fish population to effects on biodiversity of ecosystem resulting from increased competition for food and prey (Muir and Howard, 2002). Another assumed risk is by 'Trojan gene hypotheses' as per the hypotheses, the transgenic fish carrying sex chromosomes will possess enhanced mating success, but the offspring's produced will be having reduced juvenile viability. This may result in demographic destabilization and ultimately the extinction of wild species (Muir and Howard,1999; Hedrick *et al.,* 2001). Apart from the interbreeding, if we consider the potential impact of the environmental factors on the survival of transgenic and non-transgenic populations, it may or may not possess a threat to other species. In a study involving native salmon and transgenic salmon it was proved that, both the fishes coexisted and were not competing for food when food availability was high, but when the availability was reduced to 0.75% of total fish biomass, it was found that transgenic fishes were dominating the native as they were bigger in size and at the same time they were displaying strong cannibalistic behavior over their counterparts (Devlin *et al.,* 2004).

Considering these risks, the containment of transgenic fish should be the major component of any commercialization plan and at the same time a bottleneck in using transgenic fishes in Aquaculture, as fishes possess an innate ability to escape from confinement. If transgenic fishes are effectively contained, it will possess only a little risk tothe environment and wild fish stock (NRC, 2004). Bioconfinement methods or physical containment with a failsafe mechanism should be employed in transgenic fish aquaculture on approval.

III. Parasites and diseases associated with Mariculture

Asian countries contribute more than 90% of the world aquaculture production. As any other farming system, aquaculture is also affected with different parasites and diseases. This is mainly due to commercialized, intensified and unhygienic farming practices intended for making high profit. As the aquaculture industry intensifies and expands, it became susceptible to different diseases and problems caused by viruses, bacteria, fungi, parasites and other unidentified and emerging pathogens. Translocation of aquatic animals also results in introduction of parasites. Typical examples for parasite translocations with the host are as follows. In a study (Lumanlan *et al.,* 1992); it was found that imported fishes entering Philippines were infected with pathogenic parasites of protozoan genera such as *Trichodina*, *Ichtyophthirius, Cryptobia, Ichtyobodo* and *Trypanosoma; Dactylogyrus* and *Gyrodactylus; Ascocotyle* (digenean)*;* the *Bothriocephalus* (Cestode)and the *Lernaea* and *Argulus* (Crustacean). The most commonly reported monogenean parasite of grouper (*Epinephelus spp.*) and other marine fishes *Neobenedenia girellae* was introduced to Japan along with amberjack fry (*Seriola dumerili*) from Hainan and Hong Kong, China. They cause heavy infection among flounders cultured in floating net cages in 1991. In Japan, a total of fifteen cultured marine fishes were affected by *N. girellae* (Ogawa *et al.,* 1995). On introduction of the Pacific oyster (*Crassostrea gigas*) to the West coast of United States from Japan, it carried the parasite *Haplosporidium sp.* The stocks which were moved from west coast to the east of U.S was then heavily infected with the parasite and caused mortalities among eastern oysters along the eastern coast (Buresson *et al.,* 2000). Another classical example for range and distance parasites can travel along with the host is demonstrated by the WSSV affecting shrimps. The WSSV was first detected in the 1990's in Asia later on it spread to Americas by 1999 and was most recently reported in Brazil in 2005. A second important Shrimp disease Taura Syndrome (TS) caused by TSV was previously reported only in the Western hemisphere, but now it is widespread in Asia (Bondad-Reantaso *et al.,* 2005).

The Office International des Epizooties (OIE) presentlylists about 35 pathogens / diseases of finfish, molluscs and crustaceans. Of the 35 listed pathogens/diseases, 16 are diseases of finfish, 11 are affecting molluscs (other than one all are parasites) and 8 are diseases affecting crustaceans (none are of parasitic origin) (NACA/ FAO,2005). The impact of the diseases has been estimated in socio economic terms such as lose in production, income, employment, market access or market share, investment and consumer confidence, food shortages industrial failure etc. Economic impacts of aquatic animal diseases are not much analyzed and so there is not much data available, even though due to the frequency of occurrence, magnitude and spread many countries are providing some estimates of diseases in shrimp, molluscan and finfish aquaculture (Bondad -Reantaso *et al.,* 2005).

IV. Probiotics in Aquaculture

The widely accepted definition for Probiotics is the one from Fuller (1989) he defined Probiotics as a cultured product or live microbial feed complement, which usefully affects the host by improving its intestinal equilibrium. Probiotics must not be harmful to host and at the same time it should tolerate an extreme conditions such as salinity, temperature, acidity etc. The application of Probiotics can be via feed or injections as suitable (Salminen *et al.,* 1999). The Probiotics studied for use in aquaculture ranges from Bacteria (both Gram negative and positive), bacteriophages, algae (unicellular) and yeasts (Irianto and Austin, 2002). Mode of action of Probiotics contains; stimulation of humoral/cell mediate immune response, change of microbial metabolism by the increasing or decreasing of relevant enzyme levels and competitive inhibition of potential pathogens by production of inhibitory compounds or by competition for space, nutrient, oxygen etc (Fuller, 1989). However the precise mechanism of action of Probiotics is unknown, so a great deal of care should be taken in the choice of Probiotics. At the same time it should be ensured that the organism is apt for the host and free from side effects (Irianto and Austin, 2002).

V. Socioeconomic effects

Increased production of farmed fish in coastal and open ocean ecosystems has important implications on human health, employment, income and use of the marine environment.

1. Health effects

The benefits of eating fish have been fully documented and well known. The health hazards of eating farmed fish are just beginning and yet to be quantified. Farmed Salmon being a carnivorous fish that feed on the food web, and they will accumulate organic contaminants like PCBs and dioxins. The combined effects of several contaminants in a single product may pose significant threats to human health. The health benefits of consuming omega-3 polyunsaturated fatty acids will be also reduced due to the consumption of more vegetarian diet by the farmed fish (Rembold *et al.,* 2004). Salmon from Chile was found to have traces of chemicals used for the storage and preservation along with presence of malachite green, fungicide and antibiotic residue.

2. Employment and Income Effects

The net employment increases from growth in mariculture are also controversial. The Governments have often promoted mariculture for the purpose of employment and income generation, particularly in cases where wild fish stock has been declining due to overexploitation and overcapacity of vessels. Several countries started the aquaculture as an alternative avocation to the fishermen community and projected more employment and growth in the sector. Canada, Norway and Scotland initiated Salmon farming industry, but there was a mismatch in the employment and income loss from capture fisheries, which was larger than the employment and income generated in the aquaculture industry. There is no guarantee that the fishermen who lost their employment and income due to decline in the catch may get the aquaculture jobs. The Intensive aquaculture and multinational companies entering into the business usually do not benefit to the fishermen community (Naylor *et al*., 2003; Forster, 1999).

VI. Convention on Biodiversity (CBD) and Mariculture

1. Avoiding the adverse effects of mariculture on marine and coastal biodiversity

Convention on biodiversity (CBD) provided an elaborated programme of work on mariculture in relation to marine and coastal biological diversity. CBD presented the following guidelines to minimize the negative impacts of mariculture on marine and coastal biodiversity and to augment any positive effects of mariculture using native species (CBD, 2004; 2015).

1. The environmental impact assessment and monitoring procedures for mariculture developments as well as carrying capacities of the ecosystem. Need to address the likely immediate, intermediate and long term impacts on all levels of biodiversity.
2. Development of effective site selection methods, in the framework of integrated marine and coastal area management, considering the special needs and problems encountered by the stakeholders. The proper site selection for the location of cages, pens, rafts, should ensure that proper water circulation and the disbursing of nutrients and wastes.
3. Management of appropriate feeding protocol to reduce waste and environmental degradation. The workers feeding finfish and crustaceans should have proper knowledge and training to avoid work against biodiversity.
4. Development of effective methods for effluent and waste control. The organic matter accumulation may result in the eutrophication and biodiversity loss in the system. By using proper site selection and efficient mitigation process the effect on the benthos can be addressed.
5. Development of appropriate genetic resource management tactics at the hatchery level and in the breeding areas as well as cryo-preservation techniques, intended at biodiversity conservation.
6. Development of controlled low cost hatchery and genetically sound reproductive methods and these methods should be made available for widespread use, in order to avoid seed collection from nature. In case where seed collection from nature cannot be avoided, environmentally sound practices for spat collecting operation should be employed.
7. Use of selective fishing gear in order to avoid or minimize by-catch, in cases where seed is collected from the nature.
8. Use of native species and subspecies in mariculture can improve the ecosystem and marine polyculture using bivalves, seaweeds and marine finfish can reduce the waste produced in the system.
9. Implementation of effective measures to prevent the inadvertent release of mariculture species and productivepolyploidscomprising the framework of the Cartagena Protocol on Biosafety, living modified organisms (LMOS).
10. Use of proper methods of breeding and proper places of releasing in order to protect genetic diversity.
11. Minimize the use of antibiotics through better husbandry techniques. Vaccination for major diseases like furunculosis, vibriosisand yersisniosis of salmon displayed a decrease in the use of antibiotics.
12. Make sure that fish stocks used for fish meal and fish oil are managed in such a way as to be sustainable and to conserve the trophic web.
13. Use selective methods in industrial fisheries to avoid or minimize by-catch.
14. In view of Indigenous Traditional Knowledge (ITK) where applicable as a source to develop sustainable mariculture techniques.

15. Enhance the positive effects of mariculture on marine biodiversity and coastal productivity. Best site selection could actually promote the total productivity in the oligotrophic and mesotrophic system.

16. Principles, standards and certification of mariculture and mariculture products in relation to biodiversity should be developed in accordance with international standards for environmental protection.

17. Implementation of Article 9 of the code of conduct for responsible fisheries and other provision of the code dealing with aquaculture by developing necessary guidelines and legislative policy framework at the regional, national and international levels.

18. Certain precautions to elude the bad effects of GMOs are to limit transgenic to land based closed circulation setups; limit the production of sterile individuals; monosex culture and sterile culture; avoid manipulation of temperature and salinity tolerance tests to avoid the escape of species which have substantial invasive potential (Helfman, 2007).

Sustainable Mariculture

For aneffectivemariculture industry, major objectives recommended are the expansion of farming of lower trophic level fishes, reduction of fish meal and fish oil inputs in feed, development of integrated farming systems, promotion of environmentally sound mariculture practices for resource management and succeeding sustainability in conservation of biodiversity (Naylor *et al.,* 2000).It is well known that many of the capture fisheries resources are declining and mariculture seem to be the only substitute to increase the fish production from the sea. Mariculture with finest scientific and technological backup with public and private sector business approach, based on an ecosystem based management principles is the need of the hour.

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