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TRAINING MANUAL ON

OPEN SEA CAGE CULTURE

NOVEMBER 13-19, 2017

Karwar Research Centre, ICAR-Central Marine Fisheries Research Institute
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1. Overview on cage culture

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Introduction

Cage culture is an age old practice of fish farming initiated in Southeast Asian countries and later spread to the entire world. It includes traditional artisanal cages in developing countries to the highly sophisticated industrial cages in developed nations. Cage culture is a method of rearing/ growing fish in containers enclosed at all sides and bottom by net that hold the fish inside and at the same time permit free water exchange and metabolic and feed waste removal. Central Marine Fisheries Research Institute (CMFRI) has initiated open sea cage farming as an R&D effort during 2006-07 with support from Ministry of Agriculture, Government of India. As first step an indigenous cage of 15m diameter was launched at Visakhapatnam with primitive mooring techniques seabass seed, then 6 m diameter cages were designed to cater to the needs of small farmers. The mooring and other aspects were also suitably modified. The volume of each cage is about 170 m^3 and production potential is about 3-5 t of fish. Nationwide demonstrations with different social engineering, environmental conditions and species of local importance were held to bring awareness and exposure to fishers, farmers, entrepreneurs, researchers, and government agencies. This has proved highly successful by seeing the slowly growing interest among all sections as inevitable to utilize the opportunity of seas, although belated.

Cage Fabrication and Mooring

Net Cages/ enclosures are fixed/ tied to frames of varying materials. The cage frames can be fabricated using different types of materials like, wood, PVC, HDPE, GI *etc.* Depending on the capital investment the size and material can be determined. Different shapes are also used for cage frame. However, in open sea and water bodies where, more wind, wave and current action are there, circular cages are ideal for its durability. Circular shape also is advantageous in utilizing the entire water column by the stocked animals. In square cages, the corner spaces are wasted without being utilized by the cultured fish. The size of cage can also be varied as per the depth of water body available for farming. In open waters with a depth of more than 8 m, 6 m diameter cage with 6 m net depth can be used. Depending on the depth of the water, the size of cage can be altered from 2m diameter to 10 m or even 15 m. If bigger size cages are used, manoeuvring is quite difficult in open waters. Such large size cages are better only if mechanisation and automation are possible, which is not there in Indian conditions.

The conditions for selecting a material for cage frame and net fabrication are:

- Should be durable and strong, preferably light weight
- Allow free exchange of water and waste
- Not cause any stress to the stocked animals
- Should withstand/ resist fouling

- Should be cost-effective and readily available

- Three types of nets are usually employed in cage culture:
- Inner grow-out net (mesh size varying from 16 to 40 mm) depending on the fish stock
- Outer predator protection net (mesh size of 40 mm and above)
- Bird protection net (mesh size of 80 mm and above)

The floating cage frame should have outer and inner collar rings which are used for tying nets and support to the entire structure. There should be service systems like cat-walk and hand rail for safety as well as feeding convenience in open systems. The structure should withstand the vagaries of nature as well as water current and wind force. Floats and anchors are also essential for mooring and locating the cage in open waters.

Mooring/ anchoring of cages

- While mooring cage at a particular site, it should have good water circulation, but protected from strong currents and waves
- Should be away from pollution sources and agricultural waste run off
- The water depth should be in such a way that there is a bottom clearance of minimum 0.5 m to 1 m.
- Should be easily accessible to facilitate daily maintenance and feeding

- It should be easy to monitor to ensure safety and security to the cages

Mooring can be done by single point system, where the cage rotates around a single point, facilitating wastes not being deposited in the bottom at a single point and adequate water exchange. Single point mooring is ideal for sea cage systems. Fixed mooring can be practices at sites where the water body does not have adequate space available for rotation. In fixed mooring, poles are fixed at different points to tie the cage. In this system, the cage does not move from the place of mooring. Fixed mooring can be effectively followed for small cages as well as inland water systems including backwaters and rivers.

Species selection

Species selection for cage culture is mainly based on seed availability, growth rate and market value. CMFRI has done cage culture of different finfishes and shellfishes and it has been observed that, among finfishes, seabass is ideal for cage culture because of its faster growth rate and good market value. Pearl spot was found ideal for Kerala backwaters due to its low maintenance cost, comparatively faster growth rate and excellent market demand. Mullet is also good for Kerala because of its excellent local demand. Lobster is ideal for Kanyakumari, Gujarat, Chennai and Mumbai. Red snappers are also good for cage culture.

Pompano

Cobia

Fish stocking

Normally cage culture is a high density farming system where maximum production is obtained at minimum period of culture. However, stocking density depends on the carrying capacity of the system as well as cages. Stocking in a cage is dependent on cage volume. For freshwater fishes like carps, tilapia and catfish, the stocking density in cage can range from 75-80 nos/m3. A 15 m dia cage can be stocked with 30,000 juveniles of seabass *L. calcarifer* for a culture duration lasting 6- 8 months. While, in a 6 m dia cage 5,000-10,000 numbers of seabass can be stocked, depending on the harvesting size/ duration. The optimum production with such a stocking level is 3 to 5 tonnes. The mean harvest size of the stock range from 800 to 1000 g in 6- 8 months. For seabass CMFRI has experimented with fish weighing from 4 g to 300 g in open sea cages. It is important to stock approximately the same size fish to avoid cannibalism. Stocking size can vary from 15- 30 g. However, it should not be less than 15 g, larger size fishes for eg. Asian seabass weighing above 100 g will attain 1 kg in another 4-5 months grow-out in cage. Stocking beyond the capacity might lead to stress and disease in cage farmed animals. In a well managed cage even upto 98% survival can be obtained.

Feeding

Many biological, climatic, environmental and economic factors affect feeding of fish in the cages. Growth rate is affected by feeding intensity and feeding time. Each species varies in maximum food intake, feeding frequency, digestibility and conversion efficiency. These in turn affect the net yield, survival rates, size of fish and overall production from the cage. Trash fish is the main feed for seabass, grouper, bream, snapper and other carnivorous fish species cultured in marine cages. The shortage of trash fish is a major problem in many countries with large scale cage farming. Fish must be fed daily in cages with adequate quantity of good quality feed. For fishes other than omnivores and herbivores, sufficient quantity of feed has to be supplied in the cage. Floating feeding rings can be used for floating feed broadcasting inside the cage. For sinking feeds, feed trays can be installed at the bottom of the cage. Feeding rate is based on biomass varying from 4-8%. The total ration per day can be divided into equal portions and fed at different times during the day. Feeding behaviour has to be monitored daily to know any stress factor, water quality issues, diseases etc.

Fouling and Net exchange

Net exchange is a concern at places where fouling is a problem. By trial and error, CMFRI has perfected the technique of net exchange in the site itself. Net exchange is also essential during the course of fish growth. It can be done once in a month or even beyond depending on fish size and fouling intensity. At places where oyster is a problem, net exchange has to be done immediately after the spat fall.

Harvest

Harvest in cages is decided based on the size of fish, season, market demand *etc.*

Farm management

Farm management must optimize production at minimum cost. Efficient management depends heavily on the competence and efficiency of the farm operator with regard to feeding, stocking, minimizing loss due to diseases and predators, monitoring environmental parameters and maintaining efficiency in technical facilities. Maintenance works are also very vital in cage culture.

Advantages and disadvantages of cages compared to land based structures

The advantages and disadvantages of cage culture is adjudged by its comparative performance with other land based culture systems in terms of level of technology required for construction, ease of management, adaptability, quality of the fish reared, resource use, social implications, and economic performance.

Advantages

- Construction of cage is comparatively easy, be it artisanal type or modern sophisticated ones.
- Observation of the stock is easy in cages, therefore feeding and routine management is easy
- Cage reared fish are superior in quality in terms of condition factor, appearance and taste
- Cages make use of existing water bodies and thus it can be given to non-land owned people of the community (fishermen) whose income is affected by many reasons in fishing sector. It therefore acts as an alternative income for such groups.
- Harvesting is typically less labour intensive in cages
- Fish are protected from predators and competitors

Disadvantages

- Pond fish can make use of naturally occurring food, while cage grown fish only have a limited access to natural food since they cannot forage on their own. Cage grown fish therefore needs to be fed by you to a much higher extent. The food that you give your cage grown fish also has to be nutritionally complete, *e.g.* contain proper amounts of all necessary vitamins and minerals.

- When fish grown in cages instead of ponds, most farmers opt for a high stocking density. A high stocking density creates a stressful environment for the fish and stress damages the immune system. The risk of disease is therefore high. The risks will be increased further if the farmer fails to provide the fish with optimal water conditions and a satisfactory diet. Cage culture can introduce or disrupt disease and parasite cycles, change the aquatic flora and fauna and alter the behaviour and distribution of loc fauna
- If proper water exchange is not there, the uneaten feed and metabolic waste released from cages will lead to eutrophication of the site.
- Predators can be attracted to the cages and for that additional protection has to be provided such as predator nets
- Poaching is easy because fish are confined in a small area
- Marine cages face problems like fouling and is more expensive
- Storms can damage the cages.
- When cages are installed indiscriminately, its impact on environment and biodiversity is adverse and it will have influence on current flow and increase local sedimentation

- Since cages occupy open water sources, it may affect navigation in the area, or reduce landscape value of that area and are vulnerable to pollution from any source.

Current Status of cage farming

In India, sea cage farming has been initiated in participatory mode and there are about 1500 cages installed in open waters in the country including sea and coastal waters and estuaries. It is also heartening to note that DADF of Ministry of Agriculture and Farmers Welfare has allotted funds for setting up about 1000 sea cage units in different maritime states of India in collaboration with CMFRI under the blue revolution scheme. The National Fisheries Development Board (NFDB), Hyderabad is offering a subsidy of 40% in all aspects of sea cage culture like cage frame, seed, feed etc and has recognized sea cage farming as a Scheme. These steps will go long way in the development of mariculture in India which in nascent stage at present.

2. Cage Farming Of Marine Finfish and Management Practices

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Marine cage farming originated initially in Asian region almost two centuries ago but commercial cage farming pioneered in Norway in 1970's with salmon culture as the major cultivable species. In most of the Asian countries, cage culture operations were carried as traditional farming, whereas, in America and Europe large scale salmon and trout culture with modern technologies were adopted. It is been forecasted that consumption of fish will increase will be 57 % by 2020 in developing countries, whereas, the increase will be about 4 % only in developed countries (Delgado *et al.*, 2003). Among the cage culture producing countries world widely, Norway is leading, with a production of 6,52,306 tonnes with 27.5 % of total production, followed by Chile (24.8 %), China (12.1%), Japan (11.3%), United Kingdom (5.5%), Canada (4.2 %), Greece 3.2 %) Turkey (2.9%) Republic Korea (1.3%) and Denmark (1.3%) (Tacon and Halwart, 2007). Most commercially important finfish cultured in cages globally include Atlantic salmon, Coho, Chinook Salmon, Japanese Amberjack, Red seabream, yellow croaker, European seabass, gillhead seabream, cobia and rainbow trout). Altogether, 40 families of fish are estimated as cultured in cages among which 5 families (Salmonidae, Sparidae, Carangidae, Pangasiidae and Cichlidae) represent 90 % of the total production and only one family ? dominates with 66% of production. Among 80 species that are under cage culture, *Salmo salar* dominates with 51% of the total production (Tacon and Halwart, 2007).

In India, fishery sector was established as major industry six decades ago which created a potential income generation among coastal communities and contributed 5% of India's GDP during 2008-2009. In India, approximately 40,56,213 fisher folk depend on the fisheries sector for their livelihoods. In recent years, inspite of more inputs showed capture fisheries signs of slowing down, resulting in income loss to the fishermen community. Marine fish production in India declined gradually from 71% (1950-51) to 38.16% (2008-09) and capture fisheries reached a stagnation phase India has a vast coastline of 8129 km with an Exclusive Economic Zone (EEZ) of 2.02 million km^2, suitable for capture as well as culture fisheries and there is a need to look for an alternate which supplement the fishery sector.. Hence, to reach the demand of local coastal communities and also to improve the nutritional and export value of the country, cage culture became an alternate source, which can improve the socio-economic status of the fisher folk. India having a vast coastline of 8129 km, including that of the Islands, where large number of protected bays with good depth are available in coastal waters, multispecies cage farming can be developed in a commercial way. In view of the demand from the fishery sector, Central Marine Fisheries Research Institute initiated cage farming in India as an R & D activity. CMFRI perfected Cage farming technology in India viz., cage designing, nursery rearing, growout and harvest technologies for Asian seabass (*Lates calcarifer*), Cobia, (*Rachycentron canadum*) and Pompano, (*Trachinotus blochi*).

Research and Developmental work to establish open sea cage farming was initiated in the country by CMFRI in 2007 with the help of DAHDF, Ministry of Agriculture, Government of India. Cage culture was carried out at 14 different locations along both west and East coast of the country, starting from Veraval in Gujarat to Balasore in Orissa. The experiments resulted in varying levels of success at different locations in terms of the site, cage, species cultured and feed used. Asian seabass culture has been carried out on experimental basis at different location along Indian coast viz., Balasore, Karwar, Mangalore, Kochi, Kannyakumari, Chennai, Mandapam, Visakhapatnam with a Stocking density of 14 nos/m^3 (12 cm; 10 g fingerlings) and the cultured for a period of 6 months in 6 m dia. HDPE cages and recorded successful production from different areas and the production varied between 1 tonne to 5 tonnes per cage.

Based on the success in cage farming of Asian seabass in different areas in India, Karwar research Centre focused on development of a marine farm at Karwar. KRC initiated cage farming with the culture of Asian seabass in 6 m dia HDPE cages during 2009 and recorded an average weight of 2.5 kg after eleven months of culture period with FCR 1 :2.8. KRC further expanded culture of asian seabass, cobia, pompano and snappers cages with different sizes, 3 m, 6 m, 10 m and 15 m dia GI cages and established a marine farm at Karwar with 30 numbers of cages.

Marine Research Farm of Karwar Research Centre of CMFRI at Karwar

For culture of Asian seabass, circular cages of 6 m diameter made of either HDPE or 'B' class epoxy painted GI pipes are used. While HDPE cages are floated by inserting thermocol inside the pipes, GI cages are floated by providing eight pressurised fiber barrels containing 30 pounds air. Each cage is moored with concrete blocks weighing 3 t. The depth of the water column is 12 m and 10 m during high and low tides respectively. The cages are tied with HDPE inner net of 4.5 m depth and a braided outer net of 5 m depth. Both the nets are kept in circular shape by providing a ballast pipe of 2" dia, at the bottom of each net, insert with an iron rope (1.5" dia). Mesh size of outer net is 60 mm. The mesh size of the inner net employed during the first 75 days of rearing period is 14 mm and later replaced with a net of 28 mm mesh size for the rest of the culture period.

Hatchery produced Asian seabass (9±0.6 cm) reared in marine hatchery complex at Karwar are transported to the marine farm site of the Central Marine Fisheries Research Institute (CMFRI), of Karwar, and stocked in four cages @ 14 nos/m^3. The fish are fed with fresh or frozen chopped oil sardines (*Sardinella longiceps*) at the rate of approximately 10% of the biomass. Water and sediment quality parameters and also fish growth and health are monitored at weekly intervals. Growth parameters like weight (g), weight gain (g), absolute growth (AG), absolute growth rate (AGR), relative growth (RG), relative growth rate (RGR) and specific growth rate (SGR) are calculated using the following formulae and also estimated the total Biomass and Biomass increase and also total production of the culture.

AG (g) =W2−W1

AGR (g day-1) = (W2−W1)/(t2−t1)

RG = (W2−W1) / W1

RGR = (W2−W1) / W1 x (t2−t1)

SGR (%day-1) = 100 x (log W2−log W1) / (t2−t1)

where, W2 is the mean final body weight, W1 is the mean initial body weight and t2-t1 represents the number of days between samplings.

Monthly FCR values are estimated using the formula: FCR = TFC / BI where, TFC is the total amount of feed consumed (kg) and BI is the biomass increase.

The fishes are cultured for a period of 6 months and the average weight of fish at the time of harvest is 1.5 kg and total biomass is 35 kg / m^3. Culture of Asian seabass with different stocking densities are tried in 6 m dia cages and found that stocking density 14 nos/m^3as ideal for seabass culture, with 70% survival and 1 tonne of production from each cage.

Growth measurements of Asian seabass on cage site

Asian Seabass, *Lates calcarifer* cultured in 6 m dia cages at Karwar

Cobia, *Rachycentron canadum* is another potential species for cage farming in India and was initiated at Karwar in 2011. Fingerlings of cobia with an average size of 15 g were brought from Mandapam Regional Centre of CMFRI. The fish were packed in polythene bags (10 fish bag-1) containing 5 l of seawater (temperature: 20 °C; salinity: 32‰; pH: 8.2) and transported by road. The transit time is 20 h. On arrival, the fish are acclimatised and stocked in two cages and reared in nursery rearing tanks in Marine hatchery at Karwar till they attain 50 g size and then the fish were transferred to 6 m dia. cages with a stocking density of 4 numbers / m^3. After two months of culture, fish were transferred to 10 m dia. cage with the same stocking density. Fish were fed twice daily with fresh chopped oil sardine (*Sardinella longiceps*) at the rate of 6% of biomass per day for the first 3 months. The feeding rate was reduced by 2% every 3 months for the following period. Growth parameters and environmental parameters are monitored at weekly intervals. Cobia are cultured for a period of one year and a record growth of 25 kg with FCR 1:1.6 was achieved. In 6 months of culture, cobia attained an average weight of 3 kg and production was of 42 kg / m^3.




Cobia, *Rachycentron canadum* cultured in 10 m dia cage in open seawaters off Karwar

Pompano, *Trachinotus blochi* is another important species that can be cultured in both marine and brackishwater bodies. But the growth rate of Pompano is more in low saline waters. Few experiential trials were carried out at Karwar on the growth of pompano for three consecutive years. Pompano seed were transported Mandapam Regional Centre of CMFRI and were stocked in 6 m dia steel cages @ 25 numbers / m^3 The fish were fed with oil sardine in the first year and found very low growth rate at 240 days of culture. In the consecutive years trials were made with pellet feed and fed with different diets and compositions and recorded an average weight of 350 g after 6 months of culture period when fed with Growell feed @ 6 % biomass.


Growth measurements Harvest of Pompano

Snappers, are also found to be one of the most potential species for cage farming in India. Due to the non availability of hatchery produced seed in India, the culture of snappers (*Lutjanus argentimaculatus* and *L. Johnii*) is done at Karwar as capture based aquaculture. Wild seed of snappers collected from karwar as well as Mumbai and transported to the marine farm and stocked in 6 m dia. cages with initial size of 4 g and density of 30 numbers/m^3. Fishes were fed with oil sardine @ 10 % biomass and are cultured for a period of one year and recorded an average weight of 1.5 kg with a production of 30 kg/m^3.

Growth measurements of *Lutjanus argentimaculatus* and *L. Johnii* cultured in 6m dia steel cages under capture based aquaculture at Karwar

Cage cultured *L. argentimaculatus*

Marine cage aquaculture industry is gaining greater demand worldwide, due to its contribution as an alternate livelihood and also because of its protein and export value, for coastal communities. Water quality is the most important determinant for maintaining sustainable marine cage farming. The most important physico-chemical and biological parameters to be considered in cage aquaculture include water temperature, turbidity, salinity, pH, dissolved oxygen, ammonia, nitrates, nitrites, phosphates and algal blooms. It is also understood that the effects of marine finfish cage aquaculture on water quality are of great concern to the development of an ecologically viable mariculture industry. In India, cage farming of marine finfish is successful with a record production of Asian seabass, *Lates calcarifer* and cobia, *Rachycentron canadum* in 6 m and 10 m dia. steel cages respectively. To achieve a sustainable culture of these species, management of good water quality in the cage farm is of prime importance. This chapter summarizes the most predominant water quality parameters which are to be considered for management of marine cage farming.

Temperature: Water temperature has the maximum effect on fish and can be considered as a primary factor affecting the economic feasibility of a commercial aquaculture venture. Extreme temperatures can induce stress in the animal, and the metabolic activities of fish are affected, which ultimately affects the growth and health of fish. In cage culture, optimum water temperature depends on the type of cultivable species i.e., 26–32°C for most tropical species and 20–28 °C for most temperate species. Some of the fish species can survive even at varied temperatures but the growth of the fish may be affected due to temperature fluctuations. The sudden change in water temperature will affect fish metabolism, oxygen consumption, ammonia and carbon dioxide production, feeding rate, food conversion, as well as fish growth. The best solution is to select fast growing species and avoid the culture period during the months with unsuitable temperature.

Salinity: Salinity is the most important factor which can influence the ionic balance in the fish and extreme changes in salinity values further affect the growth of fish. In general, the optimum salinity required for cage culture of finfishes ranges between 10-30 ppt. However, the optimum salinity varies with the type of species cultured. Asian seabass can tolerate salinity ranging between 0-33 ppt, whereas, the salinity tolerance of cobia, pompano, snappers and groupers range between 15-35 ppt, 5-35 ppt, 15-33 ppt and 10-33 ppt respectively. Optimum salinity required for culture of Asian seabass, cobia, pompano, snappers and groupers, which are the potential candidate species for cage farming in India, are 15, 25, 15, 25 and 15 ppt respectively. It is suggested to have the culture of these species during the suitable season required for these fishes and also the area suitable and kind of water bodies. It is also suggested to culture Asian seabass in marine as well as brackishwater bodies, as the species can tolerate extreme salinity conditions. The culture of Asian seabass can be practised as in brackishwater areas and in controlled pond conditions as coastal farming. Cobia farming can be done preferably in marine water bodies as the growth rate of cobia is high under high saline conditions in marine water bodies. Pompano, *Trachinotus blochi*, can be cultured both in marine and brackishwater areas in cages and also in ponds as it tolerates all the salinities and the growth rate is more in brackishwater bodies.

Hydrogen ion index (pH): The suitable pH for most marine species is from 7.0 to 8.5. The pH values vary directly or indirectly with other water parameters like salinity and temperature, which also influences the dissolved oxygen and ammonia levels. Extreme values of pH can directly damage gill surfaces, leading to death of fish.

Dissolved oxygen: Dissolved oxygen is one of the prime factor that influences the fish health and growth in marine farms. DO is found to be a very essential element for the maintenance of osmotic activity and also digestion and assimilation of food. DO levels are mainly influenced by other environmental factors, such as temperature and salinity, and the levels decrease with increase in temperature and salinity. Ideal dissolved oxygen levels required for cage culture of marine fish range between 6-9 ppm. However, the oxygen consumption of fish varies, with species, the pelagic fish like snapper and seabass requiring more than demersal species such as grouper. In general, dissolved oxygen should preferably be around 6 ppm or more and never less than 4 ppm for pelagic fish or 3 ppm for demersal species. In the case of cage culture, benthic organisms and sediment wastes may also reduce the oxygen level. Depletion of DO always occurs during night time at neap tide in summer. It is a known factor that the algal community forms a net oxygen consumer and the occurrence of algal blooms more in the areas where nutrient flux is more, and this can lead to the oxygen depletion in water columns. Hence, it is always suggestible to culture the fish in the open waters with sufficient currents that can remove the settled particulate matter and wastes at the bottom.

Turbidity : Turbidity indicates the degree of optical clearness of seawater affected by the existence of dissolved matters, suspended particles and also tides and water currents. The suspended particles should be < 2 mg/L for cage farming of fish in marine waters. Fish wastes and the feed particulates are two major sources of turbidity in cage culture. Increase in turbidity of water results in decrease in light penetration, which in turn affects the phytoplankton production and may further affect photosynthesis of benthic vegetation, and this leads to an increase in microbial loads and in ammonia levels at the cage culture site. During monsoon season, more freshwater runoff will influence the turbidity of the water. Freshwater runoff due to rains may lead to leaching of heavy metals from industrial effluents and suspension of organic and inorganic solids in the water column. Deposition of solid organic and inorganic materials to the bottom, due to heavy rains, may act as substrate for fouling organisms on the nets, which further prevents proper water circulation. Suspended sediments are also responsible for choking of fish gills, and may lead to mortality due to asphyxiation. Hence, in order to avoid the settlement of suspended particles in the cage, it is preferable to have the culture at sites where high flushing rate conditions are available.

Nutrients: The ammonia-nitrogen levels in the water should be less than 0.1 mg l-1. Ammonia nitrogen levels in water increase by the decomposition of uneaten food and debris at the bottom, and can affect the fish. Normally in the coastal areas, sewage discharge and industrial pollution are the main sources of higher level of ammonia in seawater. The total inorganic nitrogen of water should be < 0.1 mg l-1 for a better fish culture operations. The excessive amount of nitrite in water leads to the oxidation of iron in fish haemoglobin, which causes hypoxia in fish. Total inorganic phosphorous plays an important role in growth of algae and other aquatic plants and it should always be < 0.015 mg l-1. Excess of phosphorous levels lead to algal blooms.

Algal blooms: A number of marine algae groups form blooms, including diatoms, Cyanobacteria, prymnesiophytes and dinoflagellates, which interfere with fish gill function. Excessive algal blooms can happen whenever the suitable conditions, such as higher light intensity, higher nutrient level, warm water temperature, stagnant hydrological conditions, prevail. Algal blooms can affect fish by damaging fish gills by clogging and they also compete with fish for dissolved oxygen during night time. Red tides commonly occur in warm water, especially during summer months. Cage site should be selected in those areas where there is no occurrence of blooms and also where the waters are stagnant.

Maintaining good water quality of the marine cage culture operations is important to maintain the ecological balance and also for the health of the cage cultured fish. For maintenance of good water quality, it is essential to monitor all the parameters, which influence the growth and health of the fish, at regular intervals throughout the culture period. It is important to develop standard protocols for water quality management for the cultivation of different species. A standard policy should be clearly developed for the water quality criteria to be considered while selecting a site for cage culture operations.

Recommendations for better management practices in cage culture

1. Selection of a suitable site with sufficient depth (6-10 m) is recommended to have better water exchange and to avoid the deposition of suspended wastes at the bottom. It also helps to avoid the contact of cage bottom to the sea floor which eliminates the bacterial interactions and benthic foulers.
2. Cages should be installed at a place where there is a continuous water current for good exchange of bottom fish wastes and suspended materials. The water current velocity should be between 0.05 m S-1 to 1 m S-1 with a tidal amplitude of < 1 m
3. To avoid the fluctuations in salinity and dissolved oxygen levels, culture of marine finfish in cages should be carried out after monsoon period and also to avoid the current velocity, which further influences deposition of suspended solids at the bottom of the cage.
4. Development of nutrient and water quality threshold values
5. Development of feeding strategies to improve the FCR and reduce the nutrient influx into the waters
6. Regular Monitoring of water quality parameters, at weekly intervals, is essential to understand the health status of the cage environment.
7. Regular net exchange, at monthly intervals, also improves the water exchange in the cages and improves the environmental health. The nets which are with biofoulers are to be brought to

the shore and should be thoroughly cleaned and can be reused.

8. Measures should be taken while using the farm vessel, and properly operated with minimum spill and leaks, which may cause pollution in the farm site, that may further lead to fish mortalities.
9. Rotation of cages should be implemented to decrease the waste deposition
10. Fish wasters, dead organisms, debris and other suspended materials must be transported to the shore and properly disposed.
11. Usage of antifouling agents must be avoided and mechanical cleaning of nets and frames is highly suggestible.
12. Integrated Multi Trophic Aquaculture (IMTA) must be practised in combination with other species like mussels and seaweeds, which filter the waste particulates and absorb dissolved nutrients.

3. Nets and netting materials for sea cage aquaculture

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Nets and the netting materials play an important role in sea cage aquaculture and farming practices. Nets are the most necessary components of cage farming since it delimits the fish stocking density. Fish stocking density depends on the net dimensions used for that particular cage.

The selection criteria for nets for the cage aquaculture:

- Cost effective and durable
- Strength to hold the large volume of fish
- Low weight and convenient to use
- Maintain designed shape
- Resistant to abrasion and Low water absorption
- Protection against predators
- Resistant to fouling and ease of cleaning

Features of open sea cage nets:

Shape and Design of the cage net: Different shapes of cages viz. circular, square and rectangular are used for stocking the culture organisms. The cage nets are designed according to the shape of the cage frame. Four types of nets are used in open sea cage culture practices. They are:

1. Outer net
2. Inner net

3. Bird net

4. Hapa net

Fig. 1.Cage with three types of nets (outer, inner and bird net)

 

(a) (b)

 

(c) (d)

Fig.2. Different kinds of sea cage nets (a. Outer net b. Inner net c. Bird net d. Hapa net)

Outer net: The outer side of the frame is fitted with UV treated braided HDPE net. It protects stock from predators. The 3-4mm UV treated braided HDPE net of 80mm mesh size is found suitable for grow out cages of seabass /cobia. The circular shaped 6-7m dia and 5-6m depth outer nets are common in use.

Depending on the size of cage frame and water depth the dimension of the net may vary. They are mounted with 14mm rope to retain the shape.

Inner net: Inner net is holding the fish under cultivation. Mesh size of the inner net is selected according to the size of the fingerlings/juveniles used. And it should also facilitate good water exchange and waste removal. Material should be strong enough to hold the fish stock up to the stage of harvesting. After attaining the required size in hatchery, fish seeds are stocked in inner cage.

Usually HDPE 0.75/ 14-20mm mesh size rectangular twisted HDPE nets are used for initial stocking in the sea (for about10-15 cm fish seeds). After one or two months they are shifted to strong circular cage made of 1.25mm or 1.5mm HDPE 22-28mm mesh size (5-6m dia. and 5-6m depth).Finally fish is shifted to 28mm mesh size braided HDPE nets till harvest. Cages usually fabricated in such a way that one meter is kept above the Sea water.

Bird net: The cage top is covered with the bird nets of mesh size of 130mm, made up of HDPE nets. The trash net or waste nylon net can also be used as a bird net. Its main purpose is to prevent birds from predating the stocked fish during initial stages.

Hapa net: For nursery rearing of smaller fish seeds, small meshed hapa nets are used.

Netting materials:

Different synthetic fibres like poly amide or nylon (PA), polyester (PES), polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP), polyvinyl alcohol (PVA) and high density poly ethylene (HDPE) are used in the fishing industry. Along with Nylon and HDPE, other materials like sapphire and dyneema materials were also tested for sea cage culture in India. Nylon is cost effective but net can be used economically, but since it is light weight, to hold the shape intact more weight has to be loaded in the ballast pipe. Sapphire is also good because of its high breaking strength compared to HDPE and nylon. Cost factor has to be considered while using sapphire or dyneema materials for net cage**.** Among these HDPE is most suitable fibre used for cage nets. They are resistant as they dont absorb water. Their resistance in marine environment and chemicals makes them perfect for open sea cages. CMFRI has used braided and twisted HDPE nets for grow out purpose. It can last for two or more seasons.

Properties of HDPE sea cage nets:

1. Withstand temperature up to 110^{0}C.
2. Resistant to chemicals, bases, acids and alcohol.
3. Higher rigidity make then fit for open sea conditions.
4. Moisture absorption is less.
5. Tensile strength is higher.
6. Breaking strength of HDPE in water will be 110% as that of dry condition but that of nylon is 85-90% only.
7. Shrinkage in water is 5-8% only where as for nylon it is 10-12%.
8. Weight in water will be same but weight of nylon in water will be 12% more.

9. Ease of handling and cleaning.
10. Rigid nature of the mesh opening enables free exchange of water.

Twine type:

Two types of twines in use are braided and twisted. The selection of twine number is very important. The size of the net twine is called twine number. Higher the weight ,breaking strength and cost, higher is the twine number.

Table1. Different size, runnage and breaking strength of HDPE Twines:

S.No	Code	Apr.Dia (mm)	Apr.Runnage (m/kg)	Apr. Br.strength (in kgs)
1	280D/1/3	0.25	11100	3
2	280/2x3	0.50	5490	6
3	280/3x3	0.75	3080	9
4	280/5x3	1.00	1890	15
5	280/6x3	1.25	1612	18
6	300D/8x3	1.50	1200	24
7	300/12x3	2.00	802	36
8	300/21x3	2.50	432	63
9	300/28x3	3.00	342	84

(Source: Handbook on open sea cage culture)

Mesh size and shape:

The size of the mesh is very important and selection of the mesh size depends on the size of the culture fish. Too small mesh size allows the net to clog and develop fouling and makes the water exchange difficult. The mesh shape is usually hexagonal or square.

Netting specification for grow out cultures of seabass and cobia:

The outer frame of cage is fitted with HDPE nets of stretched mesh size of 80mm. and the inner frame is fitted with 60 mm stretched mesh size with 4 and 5mm diameter thick twine respectively. The cage top is covered with the bird net having mesh size of 130mm, made up of HDPE. The depth of outer, inner netting is 3.25-6.25 and 3.0-6.00 meter respectively.

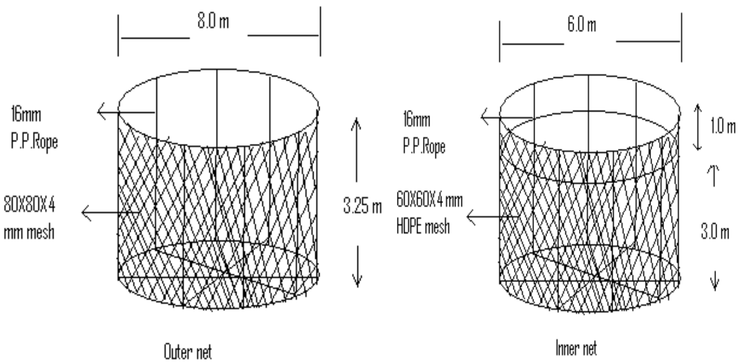

Fig.3. Depth of sea cage nets

Connecting the nets to the cage:

The inner and outer net is attached to inner and outer cage frame respectively using 4 mm size nylon rope. This rope is sewing circularly by keeping 1 foot distance to tie and detach the net easily. It also provides proper stretching and maintains shape of the cage in the sea. Perforated circular HDPE frame of 60mm diameter attached to outer netting works as ballast. It is connected to cage with 12mm nylon rope by all 4 sides to stretch the net.

Fig.4.Net preparation

Fig.5.Fixing the net to ballast   Fig.6.Cage ready for stocking

Cage maintenance:

Since the cage is installed in open sea fouling will be a regular phenomenon. Cleaning of cage frame with knife and coir should be carried out on daily basis. Checking of the outer and inner net should also be carried out on daily basis to detect any defects in nets. In addition to this, mooring system should be checked twice in a week. The regular net exchange practices should be carried out depending on the site as well as the season. It usually varies from fortnightly to monthly duration.

(A) (B) (C)

(D) (E)

Fig.7.Maintenance of sea cage nets (A. Fouled net; B.Net exchange; C. Net transportation; D. Sun drying; E. Manual cleaning)

Approximate cost of the net available for sea cage farming:

Table 2.Specifications and approximate cost Sea bass and Cobia culture nets

Net measurements	**Twine and mesh size**	**Cost (Rs)**
Outer net Dia.7mxDepth5.5m	3mm braided HDPE UV treated 80 mm mesh size	30000.00
Inner net Dia. 6mxdepth 5m	1.5mm twisted HDPE treated 28mm mesh size	18000.00
Bird prevention net	1.25mm twisted HDPE UV treated 80mm mesh size	2400.00

Table3. Specifications and approximate cost for shrimp and lobster culture nets

Net measurements	**Twine and mesh size**	**Cost (Rs)**
Outer net Dia.7mxDepth5.5m	2.5mm Braided HDPE UV treated 50 mm Mesh size	22500/-

Inner net Dia. 6mxdepth 5m	0.75mm twisted HDPE UV treated 16mm mesh size	22500/-
Bird prevention net	1.25mm twisted HDPE80mm mesh size	2400/-

In India sea cage farming is in developing state. ICAR-Central Marine Fisheries Research Institute has put pioneering research in sea cage farming and successfully demonstrated the cage culture for the fisherman and other stake holders with the recent advances and technology dissemination in cage culture in India, more and more people are coming forward to take up this activity for lively hood and industrials coming forward with net manufacturing.

4. Designing and Mooring of Net cages: Principles and types

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Global increase in fish demand with decline of fish stocks in the wild has been a motivating factor for expanding aquaculture production. Fish can be cultured in any of the four culture systems such as ponds, raceways, recirculatory systems or cages. Culturing of fishes in net cages has grown very rapidly in the recent years and is undergoing rapid changes in response to pressure from growing demand for fish and fish product. Cage represents a delineated volume in the water that confines the fish in mesh with closed enclosures. Designing and engineering is the major component for cage aquaculture. To make the cage aquaculture economically feasible, it is essential to select proper design, ideal construction material techniques, suitable mooring and good management practices.

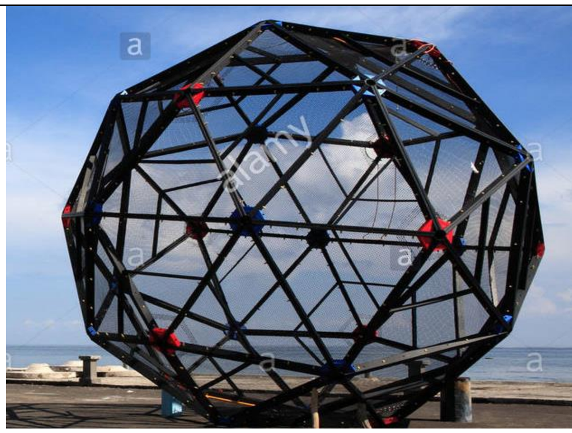
Cages for fish culture is being constructed from a variety of materials and in different shapes and size, though not all of these may prove to be effective in the intended environmental conditions and production regimes. In general the materials used for construction of net cages should be strong, durable and non-toxic. The cage must retain the fish yet allow maximum circulation of water through the cage. Adequate water circulation is critical to the health of the fish, in bringing oxygen into the cage, and removing wastes from the cage. Cost of the installation and operation also plays a very critical role.

Types of cages

1. **Fixed**- these types of cages are supported by poles driven in to the bottom of the water body viz, river, lake. Fixed cages are inexpensive, simple to design, but they have limitations such as size, shape and .restricted use.
2. **Floating**- these type of cages are designed with the buoyant collar supporting the net. These cages can be made in variety of designs like square, rectangular or circular to suit the purpose of the farmer and are widely used. Rigid materials such as GI pipes, bamboos and plastic pipes can be used as frames. The floating unit consists of a number of floats below the framework to provide sufficient floatation. The types of floats used vary from ordinary oil drums to used fibreglass barrels.
3. **Submersible-** these cages relies on frame to maintain the shape. Advantage of this type is that, the position of the cage can be changed according to the weather condition.
4. **Submerged**- these types of cages are made with wooden boxes having gaps between the slots to facilitate the flow of water and are anchored to the bottom of the substratum by poles or stones.

Cage design

Design of cages is a critical factor pushes the limits of structural integrity and economic viability in aquaculture system. Design of cage is determined by the behaviour of the cultured species. For pelagic species which swim near the surface, bigger net space is required. Such fishes tend to aggregate in shoal and swim around in circular motion. Therefore, circular or hexagonal cages may be more suitable than rectangular or square cages (Fig. 1). Whereas, demersal fishes, which are less active, territorial inhabit and prefer to hide with underwater structure, the shape of the cages does not affect fish mobility. Under such circumstances, square or rectangular cages have an advantage over a circular or hexagonal one in view of easy assemblage of cages and management. From the economic point of view, the design should be technically simple, should be easily made with available materials, cost effective, should hold reasonable amount of water while permitting sufficient water exchange and hold the fish securely during the culture period. . A good design must be safe, secure and easy to operate. Design of the cage and its accessories can be tailor-made in accordance to the individual farmer's requirements.

	
Circular	Polygonal

Hexagonal	Rectangular

Figure 1: Different cage designs (Source: CMFRI Hand book on Open Sea cage culture and Internet)

Size

Size of the cage depends on the site, species used for culture and materials used for construction. It is a fact that cost per unit volume decrease with increasing cage size, within the limits of the materials and construction methods used. It is not economical to have a cage size beyond the physical capability of the fish farmers to handle. In tropical waters, the net could get fouled in a relatively short period of time and the weight of the net would be considerably increased rendering cleaning of the net difficult. This will also reduce the floatation of the framework on which the net are suspended. Size of the cages used in marine water is larger in size than freshwater. CMFRI has developed open sea cages of 6 m dia, 10m dia, 12 m dia and 15 m dia for grow out fish culture. Ideal size for grow out cage is 6 m due to its easy maneuvering and reduced labour (Fig 2). Size of a cage for fish culture in brackish waters and reservoirs can vary, but often multiple units are installed as a battery of cages with catwalks for easy access to the fish stock and floating huts. However, from operational and planning purposes, a cage with the dimensions: 6m (length) x 4m (width) x 4m (height) is considered as a standard unit and a battery comprises 6, 12 or 24 such cages, as per requirement. The cages in a battery are arranged in caterpillar design for better exchange of water thereby facilitating relatively high dissolved oxygen.

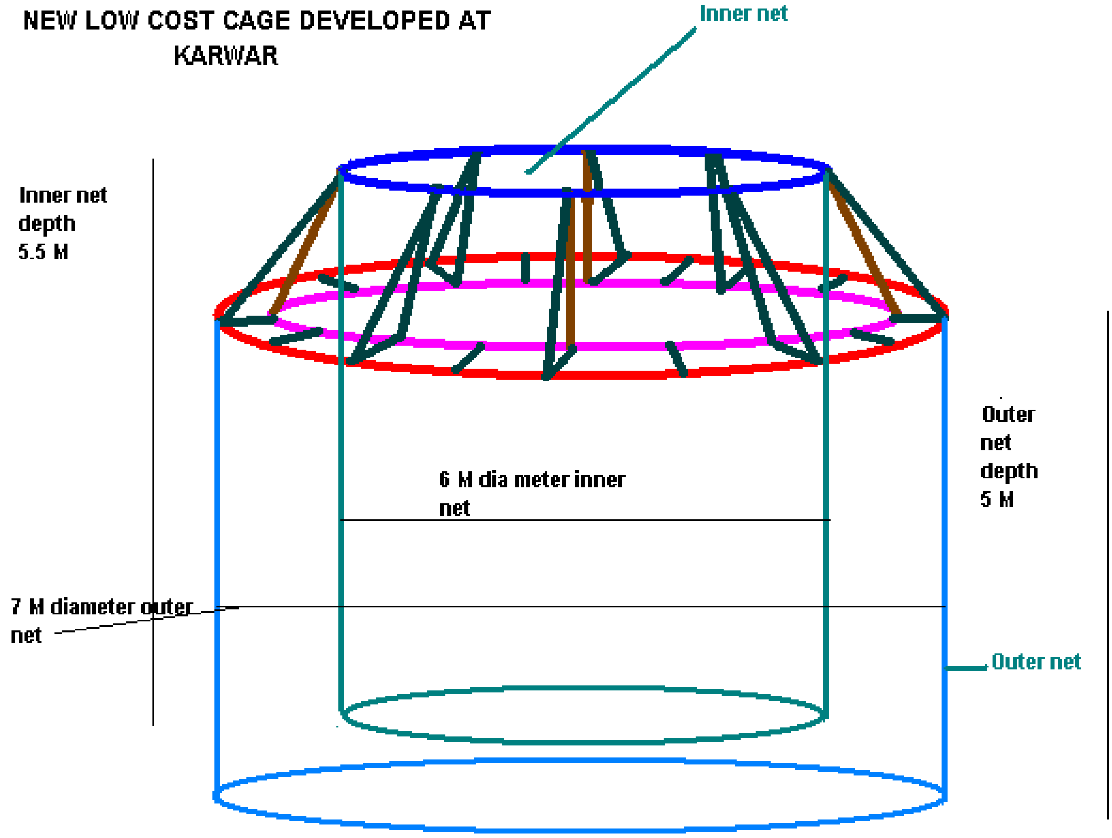


Figure 2: Low cost cage developed by CMFRI (6m dia) (Source: CMFRI Hand book on Open Sea cage culture

Shape

Cages are generally enclosed on all sides, except for leaving an opening at the top for feeding and handling the stock. Cages are of many shapes i.e., round, square or rectangular, polygonal etc. While round cages with a cylindrical net, supported by circle-shaped support frames, are extensively used for sea cage culture in India. Rectangular/square cages are used in brackish waters and reservoirs. Both round and rectangular cages are equally good from production point of view and their choice is mainly based on other considerations such as endurance (against turbulence), life, cost, availability of materials, convenience in assembling and transporting the components. However, it must be kept in mind that it is not easy to mobilize floating cranes and other logistic support for moving and installing huge structures in inland water bodies. Round cages are considered more suitable for choppy waters with wave- and wind-driven turbulence.

Materials used

Durable and stable cage materials are essential for achieving better results. Cage components consist of a frame, mesh or netting, feeding ring, lid, and flotation. Cage shape may be round, square, or rectangular. It is desirable to have environment friendly. Commonly used materials for cage frames are bamboos, mild steel (MS), galvanized iron (GI), poly-vinyl chloride (PVC) and virgin-grade HDPE (High Density 5 Polyethylene) (for runner-based & pontoon-based frames). Bamboo based frames are not recommended for commercial cage fish farming due to their poor longevity and strength to withstand turbulence. Frames of wood, iron, and steel (unless galvanized) should be coated with a water-resistant substance like epoxy, or an asphaltbased or swimming pool paint. Bolts or other fasteners used to construct the cage should be of rust-resistant materials. Flotation of the cage can be provided by styrofoam, waterproofed foam rubber, sealed PVC pipe, or plastic bottles.

Mooring

Mooring system is used to hold the cage frame in a suitable position according to the prevailing environmental conditions. A good morring system is required to keep the cages in a fixed position and to reduce the transfer of excessive forces generated by wind, currents and waves to cages. In well protected bays and seawater sites and freshwater sites, the forces of exerted by environmental factors are less and thus, small mooring system can used. In the case of sea cages, where the cages are exposed to greater environmental forces require more effective mooring systems. Mooring joints the cage with the anchor system. Type of mooring system to be used depends on the type of cage, site where the culture practices will be done, and the requirement for positional precision. Cage and mooring design is “site specific”, and careful and combined choice of cage type, nets and most specifically moorings, has a considerable bearing on the ability of fish stocks to survive in major storms, on exposed sites. Good mooring system must be

- be strong enough to resist the forces of
- Currents
- Waves and Wind action
- It should withstand and transmit the forces acting on it.

- mooring line must have high breaking strength

Mooring components

Important components include the anchor or mooring unit on the seabed, the rising line, which connects the anchor to the surface system, and the surface or subsurface mooring grid. The major elements comprise several smaller sub-units – particularly links, shackles, droppers, safety lines, buoys, etc., which in effect are integral in the complete system.

Types of mooring

- Single point
- Multipoint

Single point mooring is used with rigid collars/ frames and this system allows the cage move in a complete circle. They use less cable and chain than multiple point mooring. Reduces the net deformation than the conventional mooring. They distribute wastes over a considerably larger area than those secured by a multiple point system. The material used may be either concrete blocks (Fig. 3), or sand filled bags (Fig. 4)

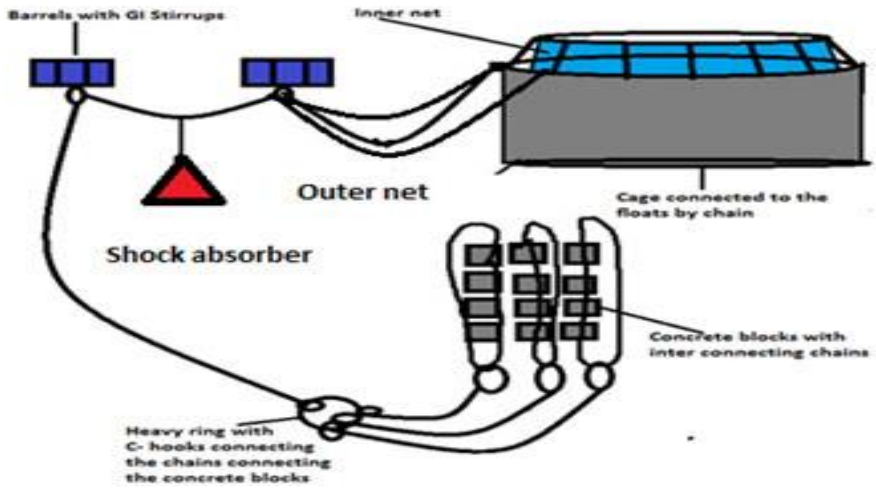


Figure 3: Single point mooring using concrete blocks (Source: CMFRI Hand book on Open Sea cage culture

Figure 4: Single point mooring using sand filled bags (Gabbion box)

Multipoint mooring is most commonly used mooring system. These systems retain the cages in one particular orientation. These systems use more chains/ropes to adopt the position of cages with least resistance to prevailing wind, wave and current forces. Orientation of cages depends on the nature of the site and group configuration of the cage

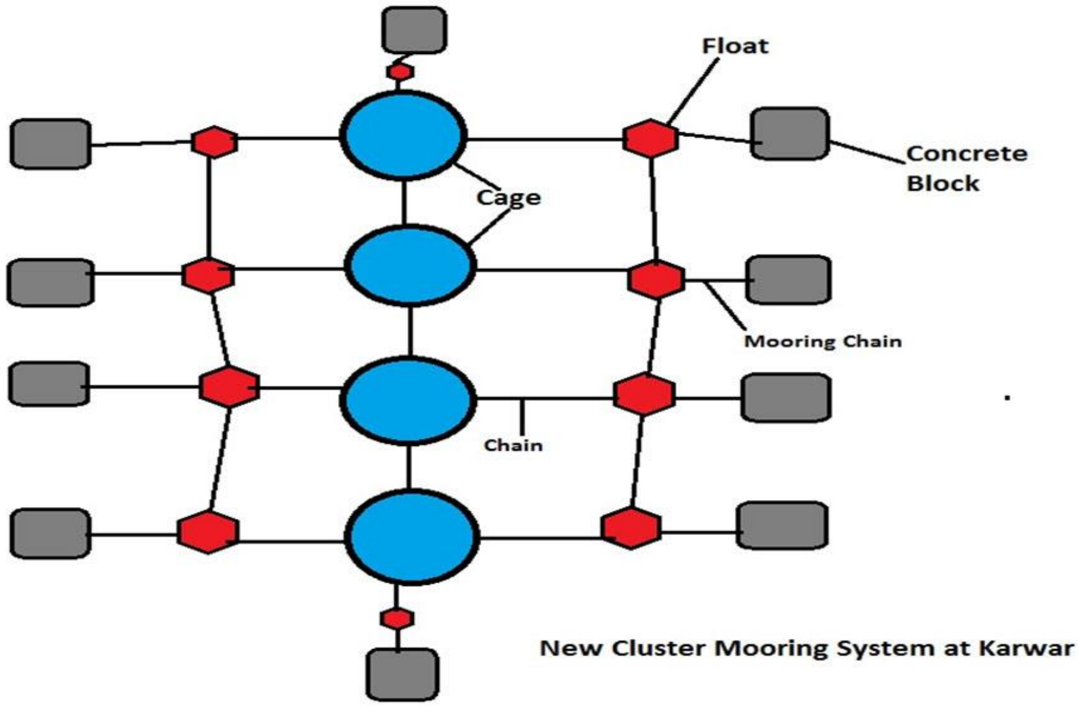


Figure 5: Multi point mooring (Source: Internet)

5. Nursery Rearing of Asian Seabass

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Seabass (*Lates calcarifer*) is an economically important food fish in many countries. This species is widely distributed in the tropical and subtropical areas of the western Pacific and Indian ocean including Australia, Southeast Asia, the Philippines and countries bordering the Arabian sea. Seabass spend most of their life in a lagoon which connects to the sea. They spend two to three more years in estuarine areas until they mature, then migrate to the sea water around the mouth of a river or lagoon for spawning. Larvae and juveniles live in the sea grass bed in coastal areas for about six months, attaining a size of about 2 to 5 inches. The fish migrate to freshwater when they grow bigger.

Why nursery rearing?

Nursery rearing of sea-bass fry in ponds and cages to stockable juvenile size is essential before release into the grow-out ponds. The nursery rearing can be carried out either in earthen ponds or indoor cement tanks or hapas. The main purpose of the nursery is to culture the fry from hatchery (1-2.5 cm in size) to juvenile size (8-10 cm). This can solve the problem of space competition in the nursery tanks. Nursery rearing is an important phase in the seed production since this transitional phase can be used for acclimatization and weaning to artificial feed and environmental conditions that could be provided in the grow-out systems. In nurseries the fry can be stocked in higher densities and reared. This would save the space and time in grow-out phase. Beyond the nursing period, the juveniles can be graded into different size groups and stocked in separate grow-out ponds. It has been observed that the juveniles from the nurseries perform better in terms of growth and survival than those stocked directly into the grow-out ponds.

Nursery pond size ranges from 1000 to 2000 m2 with a water depth of 80 – 100 cm. Pond with separate inlet and an outlet gate to facilitate water exchange is recommended. Pond bottom should be flat and sloping towards the drainage gate. Inlet and outlet gates are provided with a fine screen (1 mm mesh size) to cages can be fixed in PVC frames of floating frame, sinker and top lid. Around 2000 – 3000 fry can be stocked and monitoring of the fry is easy in net cages. Also, the maintenance cost of the net cages is lesser than the hapas. The only constraint is that, a floating feed should be used in cages for rearing sea-bass. The mesh size of the cage is 2 mm, 4 mm, 6 mm and 8 mm. The fry will grow faster in net cages than hapas as it facilitates more aerations and water circulation movements inside the cages. The best nursing of sea-bass fry is nursing in tanks. Cement tanks supplied with oxygen and drain pipes are used for nursing of the fry.

From the hatchery the fry are transported to nursery site. In transporting by truck, a mixture of crushed ice and sawdust is needed to control the water temperature in the plastic bags during transport. The mixture is spread uniformly on the floor of the truck before the plastic bags are laid upon it. The proportion of crushed ice and sawdust is 1:1 for long period transport (12–16 hours) and 1:2 for short period (4–5 hours). Transportation should be carried out at night time. By this method, it is possible to control the water temperature between 19–23°C.

Nursery rearing in indoor cement/FRP tanks

Rearing system: Immediately on arrival, the fries are given a fresh water dip and placed in cement tanks of 10' X 6' X 5' containing 7000 l of sea water. 2500 fingerlings can be reared in a tank of this size. Continuous aeration is to be ensured. The juveniles are reared in nursery rearing tanks up to 45 days before they are shifted to grow-out ponds or open sea cages.

Feeding regimes

During the nursery phase extruded slow sinking feed is preferred. Crumbled feed should be provided according to the requirements and subsequently the pellet size can be increased. The size of the pellet during the nursery phase is highly correlated with the mouth size of the sea-bass fry.

From second day onwards the fish are fed with commercial fish feed with a pellet size of 0.5 mm diameter at four per cent of the body weight four times a day (6.00 AM, 12.00 PM, 6.00 PM and 12.00 AM) for the first 15 days. Then the pellet size is increased to 1 mm for next 15 days while the feeding rate and frequency remains unchanged. For the remaining 15 days, the fishes are fed with a pellet size of 2 mm. Eighty per cent of the water is replaced 5 min after feeding with 20 min flow -through thereafter. It should be ensured that the feed is consumed immediately after feeding with no visible feed pellets settled at the bottom.

Water quality parameters:

Water quality parameters such as temperature, pH, salinity and oxygen are monitored daily using portable instruments, while critical parameters such as unionized ammonia (NH3) and nitrite (NO2) are measured fortnightly.

Grading and fish samplings:

Owing to the cannibalistic nature of the fish, size selection or grading is necessary during the whole nursery period. Grading of fish is done for once in every week with an automatic grader and grouped into different sizes. After grading, representative samples are collected for studying growth parameters.

The mechanical grader available in the market can be used for grading the fries. This exercise will give more survival rate with better growth as the sea-bass fry are getting the suitable feed according to their mouth size. Also, the cannibalistic characteristics will drastically come down due to timely grading.

The fishes are graded every 15 days with a grader and grouped into different sizes. After grading, representative samples are collected for studying growth parameters like Average daily growth rate (ADGR), Specific growth rate (SGR), Survival rate (SR), Biomass, Biomass increase (BI), Feed conversion ratio (FCR) and Protein efficiency ratio (PER).

6. Nutritional interventions and Feed Management in Mariculture

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In the recent past Marine fish farming has emerged as a potential food production sector in India. With a vast coast line of 8000 km, India has an immense potential for the development of mariculture. Central Marine Fisheries Research Institute (CMFRI) has initiated cage culture in India for the first time and marine cage was successfully launched at Visakhapatnam, in the east coast of India in 2007. CMFRI has taken a lead in popularizing finfish cage culture in India. In the last decade, CMFRI has made significant contributions to mariculture and hatchery technology of high value fin fish species.

Feed and seed are the two major inputs for any aquaculture practice. Nutritional status is one of the crucial factors influencing the growth and immune function of any organism. The Economics of fish farming is mainly determined by the cost of feed and the quantity of feed used for the grow out culture.

Principles of Nutrition

There are two types of feed used in fish farming such as formulated feed and low value fishes. Quantity of the feed is determined by the Nutrients present in the feed. The major macronutrients in fish feed includes proteins, carbohydrates and fats. Protein is considered as the building blocks of any living organism and in addition it helps in the growth of the organism. Amino acids are the basic units of proteins. There are mainly 10 essential amino acids which cannot be synthesised by the fish and 10 non essential amino acids that need not be supplemented through the feed.

Carbohydrates are feed ingredients that are mainly meant for energy yielding. They are having less importance in marine fish feed formulation but hey help in gelatine and pellet formation in extruded pellets. Fat is the major energy yielding component in fish feed. Fatty acids are the basic units of fat. Essential fatty acids are mainly required for fish growth. Fats yield 2.5 times more energy than carbohydrates and are thus the major source for the energy inputs for fish feed.

Vitamins and minerals are the important micronutrients required for the feed formation. Fat soluble vitamins and water soluble vitamins are the major vital inputs. Macrominerals like calcium and phosphorus are required in higher quantity and micronutrients such as copper , cobalt, iron, sulphur, iodine, magnesium, manganese and zinc are required in lesser quantity in fish feed formation.

Feed ingredients

There are mainly two types of ingredients such as Protein rich ingredients and carbohydrate rich ingredients. Protein rich ingredients include fish meal, meat products and oil cakes. Fish and fish products as animal origin input and oil cake as plant origin input. Cereals and cereal bye products are the important carbohydrate source for fish feed formulation. Fish feed formulation is for mixing feed ingredients at appropriate ratios to form a nutrient balanced feed. Feed production technology is mainly meant for producing sinking pellets, slow sinking pellets and floating pellets. Sinking pellets are mainly used for omnivorous and bottom duelling fishes. Slow sinking pellets and floating pellets are used for column feeders and surface feeders. Extrusion technique is mainly used for floating pellets.

Low value fishes

Low value fish feed resource includes cheaper fishes such as oil sardine, lesser sardine and rainbow sardine. These fishes are fed to the reared fishes either by cutting manually or with chopping machine. But they yield lower FCR generally up to 6:1 to 17:1 but in a well managed farm with minimum feed wastage, the FCR can be reduced up to 1.8:1 to 2:1.The major concerns Associated with feeding low value fishes are environmental pollution, enhanced the cost of production and depletion of natural resources.

Feed Management

The major factors associated with any feed management practice are quality of feeding and the quantity of feed provided to the system. Proportion of the nutrients, stability of the feed and palatability of the feed are the major criteria that it determines the quality of the feed. Feeding rate, Feeding frequency and the time of feeding are important for determining the quantity of feed to be provided for the fishes. Generally when the fish size increases feeding rate need to be reduced. In usual practices the juveniles are provided with feed @ 10% of body weight initially.

Which can be reduced to 2 to 3% as the fish grows. The feeding rate is also affected by the water quality parameters such as temperature, salinity, ammonia etc. Time of feeding is also an important factor that determines the feed utilisation in cage culture practices.

The total ration for each day need to be split into 2 to 4 portions for better utilisation of feed. Generally for fishes feeding is restricted in the day time and for nocturnal animals like crustaceans (prawns, crabs and lobsters) majority(70%) of the feed is given in the late evening hours(18hrs to 19 hrs).

Feeding practices of Cultivable fishes in cages

Presently very few fishes are cultivated in marine cage culture systems they includes Cobia, Pompano, Seabass, Grouper, Red snapper and Lobster.

Cobia

Cobia is the one of the most preferred marine fish for cage culture practices because of its faster growth and good meat quality. The culture practices of cobia include nursery rearing and cage culture phases. The culture is mainly based on either low value fishes or commercial feed. This fish requires a high protein diet for their growth and physiological activity because of their fast moving nature. The Optimum dietary protein and lipid level in juvenile cobia is 45% and 5 % of dry weight. Juveniles can be fed @ 10% body weight. For cage culture purpose freshly chopped oil sardine @ 6% of biomass per day can be given for the first 3 months. The feeding rate can be reduced by 2% in every 3 months for the remaining culture period. Feed can be given twice a day (6 hrs and 18 hrs).The reported FCR in cage culture is reported to be approximately 1.4 to 1.8.

Asian Seabass

Asian seabass or Bhekti is another popular fish recommended for marine fish culture. This fish is highly carnivorous and cannibalistic in nature with differential growth. Cultivation of this fish also requires a nursery phase and a cage culture phase. Cannibalism is observed mainly at a younger stage (1 to 20 cm length) or in the first two months of culture. For nursery rearing chopped and grounded Trash fish (4 to 6mm^3 size) @ 100% biomass twice daily in the first week at 9hrs and 17hrs which can be gradually reduce to 60% of the second week and 40% of the third week. For Weaning the fish, make sound to attract the fry to form an school and feeding time and place should be fixed for training the fishes to accept the feed . Seabass prefer slow sinking feed and thus the feeding should be done at a slower pace. When the fish are fed to satiation they disappear thus feeding should be stopped. First few days train them for feeding 5 to 6 times per day then reduce it to 2 times. The nursery rearing period last for 30 to 45 days. Grading is required to select uniform sized fishes for stocking into the cages. CIBA (Central Institute for Brackish water Aquaculture, Chennai) has developed Micro-diet with 45% protein and 12% liquid for Nursery rearing of Seabass.

During the Grow out phase the fish need to be fed with chopped fish twice daily in the morning 8 hrs and afternoon 17hrs @10% of total bio mass in the first 2 months. Then feeding can be reduced to once daily @5% of body mass in the afternoon. Feed should be given only when the fish swims near the surface to eat. CIBA (Central Institute for Brackish water Aquaculture, Chennai) has developed a Grow out feed containing 38% protein,8% fat with an FCR of 1.8:1.

Low value fish feeding

Feeding with commercial pelleted feed

Pompano

Pompano is a fast moving fish. It requires highly nutritive feed. During the nursery rearing phase fish can be weaned to any type of feed such as Floating pellets, sinking pellets and chopped pellets. Feeding can be done 3 to 4 times a day. CMFRI has developed a floating pellet with pellet size varying from 0.8 mm to 4.5mm size. For 1g size fish pelleted feed with Crude fat 6% and crude protein 50% can be provided and for fishes with 250 to 500 g size pelleted feed with crude fat 10% and crude protein 30% can be provided. The pelleted feed is reported to provide an FCR of 1.8:1.

For other fishes such as Red Snapper and Grouper, the cage Culture practices are being standardised with feeding trash fish.

Lobster

Fattening of lobster is practiced on experimental basis by providing Whole fish or chopped finfish or shellfish as fish feed. Lizard fish is preferred @10% of the body weight. Feed should be provided early morning (30%) and late in the evening (70 %).

7. Harvesting & Marketing of finfishes in Sea cage culture: Practical experiences

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For successful cage culture practices harvesting, post harvesting and marketing strategies need to be planned in a systematic manner based on the market needs, environmental conditions and price. Harvesting of sea cages are usually done either as partial harvest or as complete harvest. For making the crop profitable, usually the stock was harvested during the end of July when trawl ban was enforced along the west coast. Since the culture starts from the month of September (after the monsoon) complete harvesting is normally done in July during the trawl ban period. Partial harvesting was done on a daily basis and the fishes were marketed in the nearby market. Harvested fishes are usually graded and packed with ice in plastic boxes and sent to the market. As per market demand, Fully grown fishes can be harvested first. More over live fish marketing is also possible. Fishes can be marketed to cater high end cusumers to get better price. In cages partial harvesting is easier as compared to pond farming.

Best harvesting time can be determined based on the following criteria.

- After a certain period, the fish become suitable for harvesting.
- Time of harvest depends on the fish species.
- Start harvesting, when a major numbers of fish reach marketing age.
- Harvest during morning or afternoon, when temperature is low.
- After harvesting, send the fish to the market as soon as possible.
- Fishes are harvested once they attain a marketable size

Harvesting of sea bass

Harvested fishes

In cages Seabass can be harvested once it attains a weight of 1 Kg (in 135 days) and 2 kg (in 180 days). Where as in the case of Cobia the growth is much faster and thus it can be harvested after attaining a weight of 14 Kg (in 14 months) and 28 Kg (in 25 months)

Harvest in cages is very easy compared to that in ponds. Cages can be towed to a convenient place and harvest can be carried out. For flexible cages the net can be lifted and the cultured fish are collected by means of a simple scoop net. During the harvest, the inner net of the cage is lifted and fishes are harvested using scoop net. After harvest from cage, fishes are transferred to the plastic trays or boxes kept on the boat. The fishes were weighed and packed in trays with ice and fish in 1: 3 ratio:

After the harvest, the percentage of survival rate is normally calculated by the following formula.

Survival rate= No. of fish harvested / No. of fish stocked X 100

In most marine cage culture practices, the harvested fish are kept alive and transported immediately to the markets or restaurants. Preservation and processing of cultured fish will be an essential part of the culture industry.

The success of the adoption of any innovation or new technology lies in its economic performance. The rate of return per rupee invested is the economic indicator that guides the investor to choose a particular enterprise or practice. The analysis of the cage culture shows that with proper guidance and scientific monitoring cage culture can be one of the successful and promising fields for the traditional fishermen looking for livelihood alternatives in the face of declining fish catches. Cage culture may not be possible to take up at all the places. But with the help of CMFRI proper sites can be identified, studied and can be selected. Cage culture needs continuous scientific monitoring to keep the crop protected from diseases, to ensure proper growth and also to ensure good environment for the crop. CMFRI is committed to provide the fishermen all help in increasing fish production and alleviate poverty from the coastal villages.

COST ESTIMATES

Sl.	Head of expense	Cost (Rs)

No		
	Capital Expenses	
1	Cage	50,000
2	Mooring	30,000
3	Nets (2 Inner net and one outer net with ballast pipe)	70,000
4	Fish Cutting Machine (6 Nos)	2,50,000
	Total	4,00,000
	Recurring Expenses	
1	Cost of 5000 seeds @ Rs 8/seed	40,000
2	Transportation charges for the seed from Sirkazhi	30,000
3	Nursery rearing charges @ Rs.8/seed	40,000
4	Transportation from Nursery to farm	5,000
5	Cost 13 tonne oil sardine @ Rs10,000/Tonne	1,30,000
1	Labour Charges @ Rs.200 for 140 days	28000
2	Fuel Charges	20,000
3	Harvesting Charges	10,000
	Total	3,03,000

Consolidated Expenses

Sl. No	Head of expense	Cost (Rs)
1	Capital Investment	4,00,000
2	Recurring expenses	3,03,000
4	Total cost of the Project	7,03,000
Rupees Seven lakh three thousand only		

Economics (1st Year)

Sl. No	Head of expense	Cost (Rs)
1	5 Tonnes production @ Rs 200/ Kg	10,00,000
2	Recurring Expenses	3,03,000
3	25% of Capital Expenses	1,00,000
5	Total expenses	4,03,000
6	Net Income	5,97,000
Rupees Five lakh Ninety seven thousand only		

The success attained in open sea cage farming is expected to attract more entrepreneurs and fishermen and has opened up a new horizon in marine fisheries and mariculture in India. Even though the sea cage farming has been advancing in many Asian countries such as China, Indonesia, Japan, Philippines, Taiwan, Vietnam and Korea in recent years, it still remains to be commercialized in India. The Central Marine Fisheries Research Institute has been taking pioneering steps towards this direction in the past few years. The major constraint for popularization of cage farming in India is the less availability of sheltered areas which are ideally suited for sea cage farming. In this context, the development of advanced types of mooring, anchor and floating systems which can withstand the impact of adverse weather and currents will help us to venture into more unsheltered open sea areas. Hence it is felt that more technological and engineering interventions in cage farming coupled with large-scale hatchery production of high value and fast growing finishes can pave the way for the development of sea cage farming industry in our country in near future.

8. Health management in Mariculture

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Fisheries and aquaculture are rapidly developing food production sectors, providing nutritional security, contributing to the agricultural exports and providing direct or indirect employment to about fourteen million people. Constituting about 6.3% of the global fish production, the sector contributes to 1.1% of the GDP and 5.15% of the agricultural GDP. In India, the resources for fish production include rivers, reservoirs, brackish water, marine water and aquaculture/ mariculture. The mariculture production involves culturing fish and shell fish in natural water bodies, ponds, and raceways. Production of high value marine fish in cages installed in open sea and protected bays is being considered as a method of high density production utilizing natural water bodies without depending on land.

In India the marine finfish species being cultured include cobia, pompano, Asian seabass and red snappers. While hatchery technology for seed production is available for Asian seabass, pompano and cobia, other species are collected from the wild and reared in cages. Among cultured shellfishes, shrimp (*Penaeusmonodon* and *P. vannamei*) are hatchery produced while green mussels and oysters are collected from the natural beds and cultured in natural water bodies.

Pathology of fin fish diseases:

The culture of marine finfihes in India is a recent phenomenon. The cage culture in India was introduced by CMFRI during 2007. Compared to countries like Norway where cage culture was initiated in 70s, India is in its infancy in cage aquaculture. Intensive culture production induces stress on cultured fishes making them susceptible to bacterial, viral and parasitic pathogens. Most of the research reports on marine fish pathology are limited to temperate fishes like salmon and trouts. Research on fish health and welfare in cultivable tropical fishes are scanty.

Bacteria and virus are recognized as the primary etiological agents of many infectious diseases in a wide range of marine organisms. Many of the bacterial diseases in marine fish culture are caused by opportunistic bacteria present in marine waters and sediments. Ocean harborus millions of microorganisms which are crucial to nutrient recycling in marine ecosystems as they act as decomposers. But a small proportion of microorganisms are pathogenic, causing infection and mortality in wild and cultured marine fish and shellfishes.

Vibriosis: Vibriosis is a bacterial disease of fish and shellfish caused by several species of the genus Vibrio. Vibrio bacteria are ubiquitous in the marine environment and constitute normal microbiota of fish. Vibrios also cause ailments in human which are normally food-borne occurring when uncooked sea foods are consumed. The predisposing factors for the occurrence of vibriosis in cultured fish include increased water temperature and stress induced by trauma, overcrowding, handling, etc. However, highly virulent strains cause vibriosis in the absence of any predisposing factors. In India vibriosis remains a serious threat to the economy of fish cage farming (Sharma *et al*, 2013; Sharma *et al*, 2014).

Etiology: The causative organism belongs to the genus Vibrio. Generally the species predominant in the habitat where farming is being practiced is involved in the pathology. In India, the vibrio spp. which are reported to cause infection and mortality in cultured fin fish include *V. alginolyticus, V. harveyi, and V. anguillarum.*

Clinical signs and lesions:The initial signs of vibriosis in fish include darkening of the skin, anorexia and fish lying at the cage or pond bottom with inactivity. Vibriosis is typically characterized by hemorrhagic septicemia and the clinical signs are related to haemorragicsepticemia which includesulcerations, congestion and haemorrhage of skin and fins, congestion of liver, kidney and spleen and exophthalmia. The mortality rate ranges from 20 to 100% depending on the age of the fish, virulence of the organisms and associated stress factors.Microscopic lesions consist of hyperplastic epithelium and proliferative fibroblasts in the hepatic bile ducts,massive infiltration of erythrocytes so as to replace necrotic hepatic parenchyma by erythrocytes, enlargement of sinusoids and sub-capsular haemorrhage of the liver and necrosis, degeneration and inflammation in kidney parenchyma. Chronic cases are recognized by extensive granuloma in sub-mucosa of the stomach characterized by proliferation of connective tissue and new blood vessels and increased numbers of melanomacrophage centres in kidney, liver and spleen.

Diagnosis, treatment and prevention: The causative bacteria can be identified by biochemical tests, molecular tools using species specific primers and 16s rDNA amplification and sequencing using appropriate primers**.** When the farming in done in natural water bodies, contamination of the ecosystem by antibiotics limits the treatment protocols. In such cases, reducing the stress, periodical monitoring of vibrio loads of sediment and water and increasing water flow inside the cages by net exchange and relocation of cages would help in prevention of infection and reducing the mortality. Prevention of vibriosis in aquaculture is through vaccination, immunostimulation, use of probiotics and inhibition of quorum sensing.

Photobacteriosis: Photobacteriosis in marine fish is an infectious disease caused chiefly by *Photobacterium damselae* ssp. *damselae*. The disease in India has been reported cobia, Asian seabass and tiger shrimp.

Etiology: *P. damselae* subsp. *damselae* is a marine bacterium of the family *Vibrionaceae* that causes infections in a variety of marine animals and also in humans. Outbreak of mortality in cage farmed Asian seabass and cobia caused by this pathogen has been reported from India (Sharma *et al*, 2017). The pathogen is a normal inhabitant of marine sediment and causes disease in increased water temperature coupled with stress induced by husbandry practices.

Clinical signs and lesions: Signs of the disease include abnormal swimming behavior, slow-moving and leaning towards the bottom of the pond, lethargy and anorexia. Externally fish it exhibits dark discoloration of the skin and extensive hemorrhages in musculature. Internally accumulation of yellowish exudates in the abdominal cavity is a consistent feature. Extensive hemorrhages inside the stomach lining and pale and enlarged liver and congested kidney are normally seen.Microscopically, cellular degeneration, haemorrhage and infiltration by inflammatory cells in liver and kidney are reported.

Diagnosis, treatment and prevention: The organism can be confirmed by 16S rDNA sequencing and a multiplex PCR to demonstrate the presence of *UreC* gene in this species which is absent in *P. damselae* ssp. *piscicida* whose 16S sequence is similar to *P.damselae*ssp.*damselae*. Reducing the husbandry stress can help in preventing infection. No vaccines have been developed against this pathogen till date.

Viral encephalopathy and retinopathy:

Betanodavirus infection of finfish, also known as viral nervous necrosis (VNN), encephalomyelitis, and vacuolating encephalopathy and retinopathy (VER) has emerged as a major constraint to farming of a number of marine fish species. The disease is characterized by extensive mortality and presence of lesions in the central nervous system. The virus spreads both horizontally and vertically. In India, VER caused by RGNNV genotype is reported in cage and pond reared Asian seabass and cage reared cobia.

Etiology: VER is caused by betanodavirus, a fish nodavirus. The two major polypeptides of fish betanodavirus include approximately 100 kDa encoded by RNA1, and another of 42 kDa encoded by RNA2. The RNA sequence of RNA1 contains a single open reading frame that encodes “protein A”, which is the viral component of the RNA-dependent RNA polymerase with a molecular weight of 110 kDa, and this is the only enzyme encoded by this virus. Based on the phylogenetic analysis of RNA2 coat protein, fish nodavirus is classified into four genotypes and named after the fish species in which it was reported for the first time: TPNNV (Tiger Puffer Nervous Necrosis Virus, SJNNV (Striped Jack Nervous Necrosis Virus), BFNNV (Barfin Flounder Nervous Necrosis Virus) and RGNNV (Red-Spotted Grouper Nervous Necrosis Virus).

Clinical signs and lesions: The clinical signs of the disease generally include pale or dark discoloration, off feed, lethargy, and abnormal swimming behaviorwhich may include floating upside down, resting at the bottom, spinning, or abrupt whirling. Grossly, congested brain can be seen. Histologically, extensive necrosis of the central nervous system with numerous virus particles present in the cytoplasm of affected nerve cells, extensive vacuolation and neuronal degeneration of the mid and hind brain and vacuolation of the retina are reported.

***Diagnosis, treatment and prevention*:** The disease can be diagnosed based on histopathology, nested RT-PCR, electron microscopy and cell culture. Since the disease is caused by RNA virus, which can be transmitted both horizontally and vertically, the most prudent way of controlling this disease is following strict biosecurity and vaccination of the fish. Although there are a number of reports focusing on different types of vaccines for VER (recombinant protein, DNA and inactivated vaccines), there are still no commercial vaccines available. This is possibly because the disease is associated with outbreaks in larvae and juvenile fish which are normally notimmuneompetent, or other vaccine formulations/strategies are required to make the vaccines more efficacious in an aquaculture system (Costa and Thompson, 2016). The Central Marine Fisheries Research Institute has developed a single tube Reverse Transcription – Loop – mediated Isothermal Amplification (single tube RT-LAMP) for easy detection of Betanodavirus infection.

9. Farming of organic extractive species in a Multi-Trophic Aquaculture systems (IMTA)

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Aquaculture production has been responsible for the growth in the supply of fish for human consumption. During the past three decades production increased from 6.2 million tonnes in 1983 to 73.8 million tonnes in 2014(FAO, 2016).

In 2014, the aquaculture production comprised of 49.8 million tonnes of finfish, 16.1 million tonnes of molluscs, 6.9 million tonnes of crustaceans and 7.3 million tonnes of other aquatic animals including amphibians. China accounted for more than 60 % (45.5 million tonnes) of global fish production from aquaculture. Other major producers were India, Vietnam, Bangladesh and Egypt. In addition, 27.3 million tonnes of aquatic plants were cultured.

Nearly 50% of the world's aquaculture production is from non-fed species of animals and plants. This is important in terms of food security and in terms of the quality of farming environment. These species include silver and bighead carps, filter-feeding bivalve molluscs and seaweeds. However, growth in production has been faster for fed species than for non-fed species. This growth in aquaculture of fed species, has introduced many apprehensions about the environmental impacts from aquaculture waste. Intensive finfish farming in cages can release significant quantities of nutrients to the farm site, from uneaten feed, faeces and excretory products. These metabolic wastes from farm effluents, mostly ammonia, may contribute to increased nutrients and localised eutrophication in the farm. One of the major challenges for the sustainable development of aquaculture industry is to minimise environmental degradation concurrently with its expansion. Though majority of aquaculture production originate from extensive and semi-intensive farming systems, the recent increase in intensive farming of marine carnivorous fed-species is associated with environmental concerns. Integrating waste generating (fed) and cleaning (extractive) organisms in mariculture is a practical solution for sustainable mariculture. In a balanced integrated system, aquaculture effluents can be converted into commercial crops while restoring water quality.

Integrated multi-trophic aquaculture (IMTA)

In many monoculture farming systems,the fed-aquaculture species and the organic/ inorganic extractive aquaculture species (bivalves, herbivorous fishes and aquatic plants) are independently farmed in different geographical locations, resulting in pronounced shift in the environmental processes. Integrated multi-trophic aquaculture (IMTA) involves cultivating fed species with extractive species that utilize the inorganic and organic wastes from aquaculture for their growth. According to Barrington (2009), IMTA is the practice which combines, in the appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. shellfish/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental sustainability (bio-mitigation) economic stability (product diversification and risk reduction) and social acceptability (better management practices).

Selection of species

Environmental sustainability is the major consideration in IMTA, therefore the criteria guiding species selection is the imitation of natural ecosystem. Fed organisms, such as carnivorous fish and shrimp are nourished by feed, comprising of pellets or trash fish. Extractive organisms, extract their nourishment from the environment.

The two economically important cultured groups that fall into this category are bivalves and seaweed. Combinations of co-cultured species will have to be carefully selected based on1) Complementary roles with other species in the system 2) Adaptability in relation to the habitat 3) Culture technologies and site environmental conditions 4) Ability to provide both efficient and continuous bio-mitigation 5) Market demand for the species and pricing as raw material or for their derived products, 6) Commercialization potential, 7) Contribution to improved environmental performance and 8) Compatibility with a variety of social and political issues.

Fed-aquaculture sub-system in IMTA

Finfish represent the only fed component of most IMTA systems and thus represent the only human provided input of nutrient energy to the system. In their role within an IMTA system, fish provide dissolved and particulate nutrients and oxidation reduction potential reducing compounds to the other component organisms as well as revenue to the industry. The quantity and form of these nutrients is dependent on species, size and feed formulation among other factors.

Inorganic extractive sub-system in IMTA

Seaweeds are most suitable for bio-filtration because they probably have the highest productivity of all plants and can be economically cultured. Bio-filtration by aquatic plants, is assimilative, and therefore adds to the assimilative capacity of the environment for nutrients. Plant bio-filters can thus, in one step, greatly reduce the overall environmental impact of fish culture and stabilize the culture environment. Seaweeds have a large market for human consumption as phycocolloids, feed supplements, agrichemicals, nutraceuticals and pharmaceuticals. Aquatic plant farming, overwhelmingly of seaweeds, has been growing rapidly and is now practised in about 50 countries.

The choice of seaweed species for inclusion in an integrated aquaculture system must first depend upon meeting a number of basic criteria such as high growth rate and tissue nitrogen concentration; ease of cultivation and control of life cycle; resistance to epiphytes and disease-causing organisms; and a match between the ecophysiological characteristics and the growth environment. In addition, given the ecological damage that may result from the introduction of non-native organisms, the seaweed should be a local species.

Only a handful of seaweeds have been thoroughly investigated for theiraquaculture and/or bioremediation potential. Along Indian coast *Kappaphycus alvarezii* were used in IMTA and has emerged as a promising species in open sea integrated aquaculture.

Organic extractive sub-system in IMTA

In a conceptual open-water integrated culture system, filter-feeding bivalves are cultured adjacent to meshed fish cages, reducing nutrient loadings by filtering and assimilating particulate wastes (fish feed and faeces) as well as any phytoplankton production stimulated by introduced dissolved nutrient wastes. Waste nutrients, rather than being lost to the local environment, as in traditional monoculture, are removed upon harvest of the cultured bivalves. With an enhanced food supply within a fish farm, there is also potential for enhancing bivalve growth and production beyond that normally expected in local waters. Therefore, integrated culture has the potential to increase the efficiency and productivity of a fish farm while reducing waste loadings and environmental impacts.

A native bivalve species must be considered to suit the local ecology, potential markets, and the need to engineer IMTA systems to accommodate them. Literature shows that 95% of particles released from aquaculture systems, fish farms, and closed recirculation systems are ~20 microns diameter (5-200 micron range) and that they will settle. There is evidence that filter-feeders are selective in extracting particles from the water column, rejecting the rest. Thus, it is important to know the particle size of wastes from an IMTA system and to choose from among the wide range of bivalves that will select the required particle size and type.

Mussel farming

Mussels are found attached to the hard surfaces in the littoral and sub-littoral zones by secreting long fine silky threads called byssus threads. Being sedentary, they can tolerate short periods of exposure to extreme temperatures, salinities, desiccation and relatively high levels of turbidity. The two species of mussels with good potential for culture in India are the green mussel, *Perna viridis* and the brown mussel *Perna indica.*

Site-selection: The success of mussel mariculture depends largely on the selection of an ideal culture site.

- Water current: Moderate water current to provide adequate food supply
- Water Depth: The depth of water column of a location determines the type of culture method to be adopted. It can range from 1-15 m at average mean low tide.
- Salinity: Mussels grow well above 20psu, but the ideal salinity for rearing is 27-35psu.
- Turbidity: The presence of suspended particles above a certain level disrupts the filtering activity of the bivalve.

- Primary productivity and food organisms: Clear seawater with rich plankton production is considered ideal for mussel culture.
- Source of Seed: Mussel culture requires a proximity to spat or seed source, which may affect site selection criteria. However, if it has to be transported from elsewhere, it should be transported to the farm site within a reasonable time and cost.
- Pollution: The sedentary bivalve fauna is exposed to very high probability of contamination and could act as vectors due to their peculiar feeding habits and bioaccumulation potential. Bivalves are known to accumulate trace metals and pollutants, therefore the farming site should be free from pollution
- Harmful algal blooms: Another criterion of deciding the suitability of potential culture site is eliminating the threat of Harmful Algal Blooms.

Farming technique:

- **On-bottom method**: In areas where water depth is less than 1.5 m, mussels can be farmed by sowing directly on the bottom substratum/ or seabed.
- **Bouchot culture**: This method involves farming mussels in intertidal mud flats on poles combining spat collection with on growing.
- **Suspended farming methods**: For suspended farming method, the water depth can be a limiting factor as a minimum water column is essential all throughout the culture period

- **Rack method**: Suitable for estuaries and shallow seas. Bamboo or Casuarina poles are driven into the sea/ estuarine bed at a spacing of 1-2 m and are connected horizontally. Seeded ropes are suspended from the horizontal frames or in shallow areas, they are placed horizontally between the vertical poles. This method is practiced in India and Philippines in shallow waters where the depth is <1m. Due to the effective utilization of the productive upper water column this type of culture gives better yield.
- **Raft method**: This farming method is suitable in deeper open-sea conditions which is not turbulent. It consists of a square or rectangular bamboo or casuarina pole lattice structure from which ropes are hung. The raft is buoyed up by styrofoam / ferroconcrete buoys or metallic/ HDPE barrels of 200 litre capacity (metal oil barrel painted with anticorrosive paint). Ideal size of the raft is 5 x 5 m. The rafts are to be positioned at suitable location in the sea using anchors (grapnel, granite, concrete).
- **Long-line method**: Considered ideal to resist storms and wave effect, in unprotected open sea conditions and are particularly adopted in areas having high tidal amplitude. Synthetic rope of 16-20mm diameter is used for the long-line (main line). The main horizontal line is supported with floats/ buoys at every 5m. The seeded ropes are suspended from the main line 1.5-2m apart. The long-lines with floats

are anchored in position using concrete blocks and nylon ropes or metal chain at both the ends.

- **Farming area**
- Open Sea farming is practiced in areas with a depth of 5-20m. The selected area of culture should be free from strong wave action, less turbulent and with high productivity. Long line and raft culture techniques are ideal for open sea farming. Disadvantages of this type of farming are poaching, unpredicted climatic changes and predation.
- Estuarine farming when compared to the open sea, the estuarine ecosystems are less turbulent and shallow (<4m). Stake and rack culture (horizontal and vertical) are ideal for estuarine conditions. Fluctuation in salinity during monsoon season and pollution through domestic and industrial waste are the main constraints in estuarine mussel farming. On-bottom culture by relaying of mussel seed in pen enclosures is also practiced.

Seed source and seeding

Mussels are characterized by a high fecundity and a free-living larval phase. Though the key issue in mussel farming is the inconsistent or irregular spat settlement in natural beds affecting the seed supply, hatchery sources are not generally depended up on for the mussel spat. Mussel farming mainly depends on the natural spat. The spat-fall in mussel beds commences from August to December along the west coast of India, progressing from the south to the north. Mussel spats are collected by physically scrapping them from the intertidal or subtidal natural beds. Submerged beds are ideal for sourcing mussel seeds. About 500 to 750 g of 15-25 mm seeds are required for seeding 1m of the culture rope. Nylon rope of 12-14mm or 15-20mm coir rope can be used for farming. Seeding is done by placing the culture rope within the pre-stitched tubes of bio-degradable wrapping material and filled with mussel seeds. Generally, cotton mosquito nets are used for wrapping the seeds, which degenerates in 2-3 days. By this time the seeds will secrete byssus thread and will get attached to the rope.

Growth

The seed, which get attached to ropes, show faster growth in the suspended water column. If the seed is not uniformly attached, crowded portion always show slipping. To avoid slipping, periodical examination of seeded rope and thinning of the same is essential. The culture ropes also should be at least 1 m above the sea floor during extreme low water spring tides in order to prevent predators from reaching the bivalves, to avoid exposure of the molluscs to high water turbidity near the seabed and to avoid losing the bivalves at the end of the rens. The top seeded portion of the culture rope should be prevented from exposure for longer period during low tide. The mussel grows relatively fast in the suspended farming systems. They attain 80-90 mm in 5-6 months with growth rate of 8-11mm/month.

Post-harvest handling and marketing:

Mussels are harvested once they attain the marketable size and condition index is high, i.e., before the spawning and onset of monsoon. Normally harvest season is from April to June. Mussel ropes are collected manually and brought to the shore for harvest. The ropes are washed thoroughly using water jet to remove grit and silt. The mussels removed from the ropes are maintained in re-circulating seawater for 24h and are washed again in fresh seawater. This method of depuration is effective in reducing the bacterial load of the mussel meat by 90%. Depurated mussels are then sold mainly in the local market as live shell-on mussel. Meat from depurated mussel can be shucked in fresh condition or after boiling or steaming. Further processing of the mussel meat can be done after blanching in 5% salt solution for 5 minutes.

Depuration: Depuration of the harvested mussels is necessary to increase the quality of the mussel meat and to avoid the risk of consuming contaminated mussel meat. Mussels during their process of feeding, may accumulate undesirable materials including harmful microorganisms. Before the product reaches the market, it need to be ensured that the mussels are safe for human consumption. This process of purification is called depuration. The mussels are kept in cleaning tanks under a flow of filtered seawater for the period of 24h. In the depuration tanks about 10-20% of the seawater is continuously replaced. At the end of 12 hours the water in the tank is completely drained and mussels are cleaned by running water to remove the accumulated faeces. The tanks are again filled with filtered seawater and the flow is maintained for another 12 hours. Then the tanks are drained and flushed with a jet of filtered sea water. Further, the mussels are held for about one hour in seawater chlorinated at 3 ppm, and then washed in filtered seawater.

IMTA system designs

An effective IMTA operation requires the selection, arrangement and placement of various components or species, so as to capture both particulate and dissolved waste materials generated by fish farms. The selected species and system design should be engineered to optimize the recapture of waste products. As larger organic particles, such as uneaten feed and faeces, settle below the cage system, they are eaten by deposit feeders, like sea cucumbers and sea urchins. At the same time, the fine suspended particles are filtered out of the water column by filter-feeding animals like musselsand oysters. The seaweeds are placed a little farther away from the site in the direction of water flow so they can remove some of the inorganic dissolved nutrients from the water, like nitrogen and phosphorus. IMTA species should be economically viable as aquaculture products, and cultured at densities that optimize the uptake and use of waste material throughout the production cycle.

The open-sea IMTA in India is very recent; however, various investigations have been carried out on the beneficial polyculture of the various mariculture species.Finfish culture, *Etroplus suratensis*, in cages erected withinthe bivalve farms (racks) resulted in high survival rates and growth of the finfish in the cages. Co-cultivation of *Gracilaria* sp. at different stocking densities with *Feneropenaeus indicus* showed nutrient removal from shrimp culture waste by the seaweed. The ratio of 3:1 was found suitable for the co-cultivation. The seaweed (600 g) was able to reduce 25% of ammonia, 22% of nitrate and 14% of phosphate from the shrimp (200 g) waste.

Along the east coast of India, the introduction of IMTA in open sea cage farming yielded 50% higher production of seaweed, *Kappaphycus alvarezii*, when integrated with finfish farming of *Rachycentron canadum*. Open-sea mariculture of finfishes when integrated with raft culture of green mussels, *P. viridis* resulted in slight reduction in nutrients along Karnataka.

Marketability of these secondary products in IMTA is a factor, but it need not be an overriding consideration. Studies have shown that bivalves are capable of utilising fish farm wastes as an additional food supply. However, few practical studies have been undertaken, with conflicting conclusions regarding the potential for open-water integrated culture to enhance bivalve production and, by implication, to significantly reduce fish farm wastes.

Prospects:

The beneficial effect of combining bivalves such as mussels, oyster and clams as bio-filters in utilizing nutrient rich aquaculture effluents has been documented in estuaries. In a tropical integrated aquaculture system, the farming of bivalves (*Crassostrea madrasensis*) along with finfish (*Etroplus suratensis*) resulted in controlling eutrophication effectively (Viji *et al*, 2013, 2015). The bivalve mussel, *Perna viridis* and oyster *Crassostrea madrasensis* that are commercially produced along Indian coast, can economically mitigate eutrophication in integrated aquaculture.There is tremendous opportunity to use bivalves and seaweed as bio-filters and integrate with fed-aquaculture and produce products of commercial value.

10. Integrated Seaweed Farming

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Seaweeds or marine macroalgae are plant-like organisms that generally live attached to rock or other hard benthic substrata in marine environment. They are non flowering without true roots, stems, leaves and attached to substratum by means of holdfast and contribute significantly to the primary production of the marine ecosystem. They are found mainly found in intertidal and in the sub-tidal region up to a depth, where 0.01 % photosynthetic light is available. Like higher plants, these macroalgae convert carbondioxide and inorganic nutrients present in seawater to sugars and organic nutrients which form basis of life.

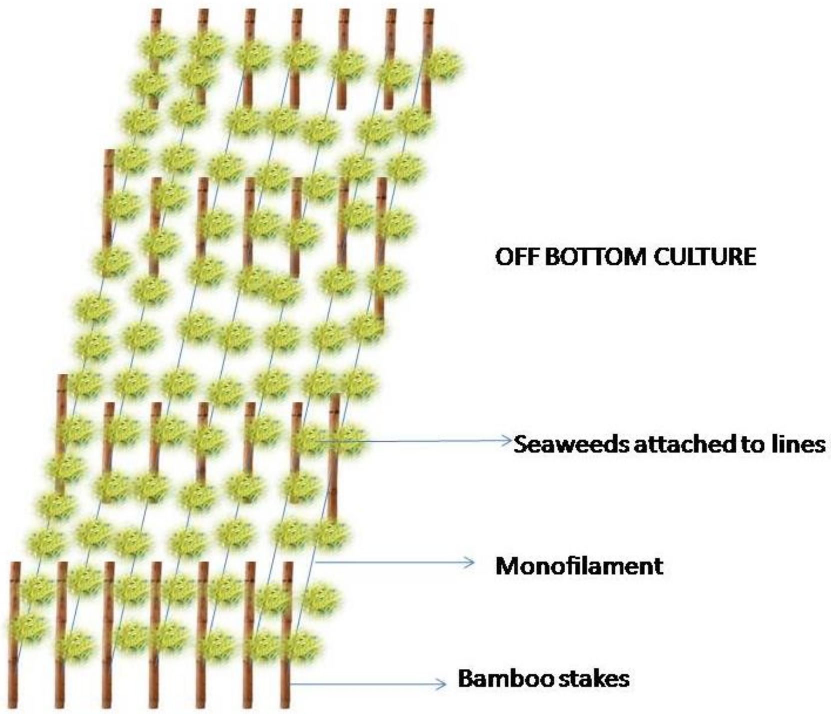
Seaweeds are classified into three broad groups based on their depending on their nutrient and chemical composition to Rhodophyceae (Red seaweed), Cholorophyceae (Green seaweed) and Phaeophyceae (Brown seaweed). Although the global diversity accounts to about 6000 species of red seaweeds, 2000 species of brown seaweeds and 1200 species of green seaweeds, only 221 species (32 green seaweeds, 64 brown seaweeds and 125 red seaweeds) are utilized commercially of which 125 species used as food and 110 species used for production of hydrocolloids.

With the global increase in demand for seaweed material for various applications, collections from the wild were not sufficient enough to meet the requirement. The culture of commercially marketed seaweeds through vegetative method of propagation is now the major means for supply of raw material to seaweed based industries.

Methods of seaweed cultivation

1. **Line cultivation:** Seaweeds are attached to ropes of varying lengths (e.g., from 10 m to 50 m or longer) that are placed in a parallel arrangement with varying spacing between them, depending on size of the seaweed species at harvest (from 0.5 m to 1.0 m or more), at depths that vary according to the following.

a. Off-bottom – planting close to the bottom near shore were 30 cm of water is available above during the lowest tide. This method is widely used with small and/or frequently harvested species, like Eucheuma and Kappaphycus.

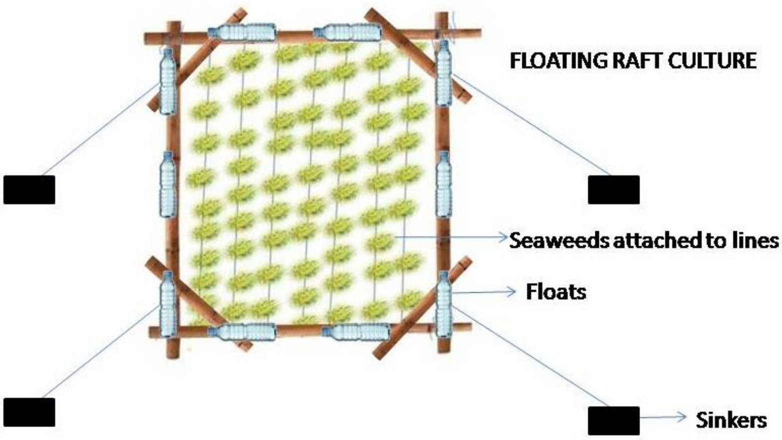


b. Submerged hanging line – planting in midwater near shore, submerged several meters at high tides and at the surface or even exposed during low tides.

c. Floating line (long-line) – planting at or close to the surface with seaweeds slightly submerged (i.e., not exposed). Excepting the need for anchoring, this method allows cultivation regardless of the depth to bottom.

2. **Net cultivation:** Seaweed propagules are attached to nets placed at a given water depth, usually floating at the surface or slightly submerged, analogous to line cultivation in relation to depth.

3. **Floating raft cultivation:** Planting occurs at the surface, attaching seaweeds to lines or nets with the shape given by a floating rigid frame made of bamboo or other material.



Among these culture methods, off bottom and floating raft methods are the popular methods for seaweed cultivation. In off-bottom method, monofilament nylon lines or polypropylene ropes are stretched (usually 1m apart) between wooden stakes driven into the sea bottom. Small pieces of seaweed are tied into the lines.

The floating raft method is suitable in protected areas where water current is weak or when the water is deep.Normally, a floating raft (typically a 3×3m square bamboo frame) with polypropylene ropes is used to suspend the seaweed about 50-cm below the surface. The seedlings are tied to the ropes and the raft is anchored to the bottom. Rafts are also constructed with net bottoms to prevent the grazing of seaweeds by fishes.

Integrated multitrophic aquaculture (IMTA)

"Integrated" refers to intensive and synergistic cultivation, using water-borne nutrient and energy transfer. Integrated aquaculture provides nutrient bioremediation capacity, mutual benefits to the cocultured organisms, economic diversification and increased profitability. It is necessary that a successful sustainable integrated farming system mimics in a way similar to functions of the natural ecosystem. "Multi-trophic" means that the various species occupy different trophic levels, i.e., different (but adjacent) links in the food chain. The species integrated belongs to different trophic levels sharing complimentary chemical and biological processes hence have balancing effect on ecosystem and improves the overall health. In integrated multi-trophic aquaculture (IMTA) the byproducts, including waste, from one aquatic species as inputs for another species integrated in the same system. These systems thereby provide environment remediation (biomitigation), economic stability (improved output, lower cost, product diversification and risk reduction) and social acceptability (better management practices).

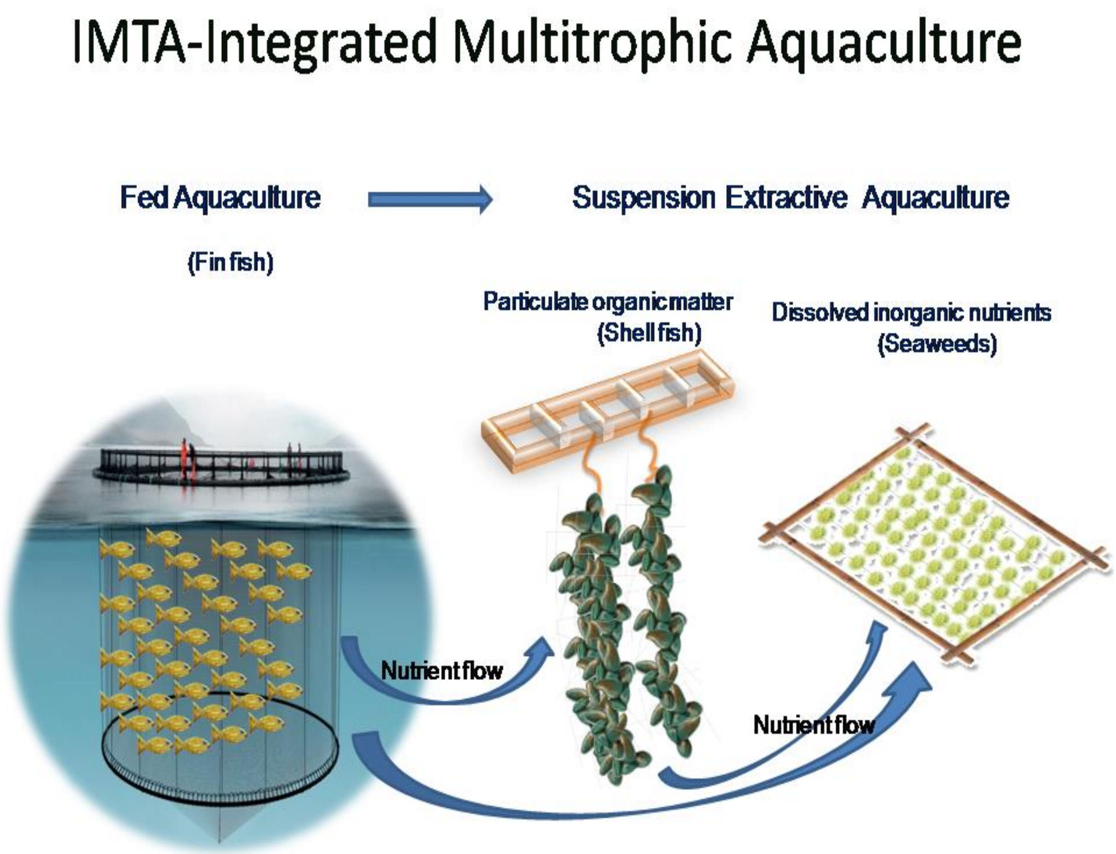
Seaweeds can be integrated alone or along with shell fish near fish cage culture thereby reducing eutrophication of the surrounding environment and increasing economic diversification. These macroalgae sequester the nutrients out of the water. Integration with seaweeds and/or filter feeders is often the only economically feasible alternative for waste treatment in open-water aquaculture systems.

Fed organisms (mainly carnivorous fish and shrimp) are nourished by feed (commercial diets or trash fish). Extractive organisms (seaweeds and bivalves), as the name implies, extract their nourishment from the environment. Bivalve (e.g., mussels, oysters and clams) build their own body while degrading suspended organic particles (uneaten feed, phytoplankton and bacteria) that they filter from the water. Seaweeds use sunlight to build their biomass, while assimilating dissolved inorganic nutrients removed from the water. These extractive organisms can turn pollutant nutrients into commercial crops and loaded effluents into clean water.

The concept of integrated aquaculture constitutes an essential element in Coastal Zone Management, aimed at reducing, in an economically and socially beneficial manner, the adverse environmental impacts of aquaculture (freshwater, saline or marine) on the coastal environment. Recycling of waste nutrients by algae and filter-feeding shellfish is the most likely way to economically improve world mariculture sustainability.

Examples of IMTA

Israel	Seabream+Ulva Abalone+Fish+Ulva Abalone+Fish+Mollusc+Ulva
Chile	Gracilaria+Turbot Macrocystis+Salmon
China	Shrimp+Crab+Seaweeds Mussel+Scallop+Laminaria/Undaria Fish+Gracilaria
Hawaii	Shrimp+Gracilaria
USA	Salmon+Porphyra
Norway	Salmon+Mussel+Laminaria
Philippine	Seabream+Eucheuma/Gracilaria
Australia	Shrimp+Oyster+Gracilaria
India (CMFRI experiments)	Cobia+Seabass+ Seaweeds/Green mussel- CMFRI, Karwar Cobia+Kappaphycus- CMFRI, Mandapam CMFRI, Veraval


IMTA-Integrated Multitrophic Aquaculture
Fed Aquaculture
Suspension Extractive Aquaculture
(Fin fish)
Particulate organic matter
(Shell fish)
Dissolved inorganic nutrients
(Seaweeds)
Nutrient flow
Nutrient flow

11. Cage Farming in Coastal waters of Karnataka

Sujitha Thomas and A.P. Dineshbabu
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In India aquaculture is done with moderate to low input and in the marine side it was restricted to shell fish farming (Shrimps, Mussels and Oysters). Recently CMFRI has initiated culturing of marine finfishes in cages and it has proven successful in many maritime states. In this the adoption of sustainable capture based aquaculture initiative by the traditional coastal fishers the state of Karnataka is noteworthy. A need assessment survey conducted along the coast of Karnataka among the fisher folks about the livelihood issues revealed that they are deprived of an alternative income during the lean fishing season (monsoon season). The fishers employed in the estuarine fisheries also found that salinity in the estuarine areas was increasing over the years and many species which were abundantly available were absent or in fewer numbers in the estuary. It is at this juncture CMFRI introduced cage culture along the coast of India. Among the three coastal districts of Karnataka, Uppunda village falls in the area where the fisherfolks are exposed to aquaculture (shrimp farming). Due to this, the adoption and farming of finfishes were successful in this area.

Estuarine and coastal waters of Karnataka is known for the abundance of finfish seeds of mullets, sand whiting, pearlspot, milkfish, Indian terapon, butterfish and flatfishes. During June-

September, juveniles of a number of cultivable species of finfishes like *Lutjanus* spp. *Gerres* spp., *Etroplus* spp. are caught in the seines, cast nets and gillnets operated along the coast. Usually these juveniles are discarded or are sold at a low price. An attempt was made to popularize the concept of capture based aquaculture (CBA) by judiciously utilizing these seed resources. The success of the CBA has encouraged more fishermen to venture into cage farming.

Major aspects of cage culture in estuaries are selection of site for cage culture, species, selection and materials for cage construction. Care has to be taken to see that the cage are constructed from the materials which is locally available and affordable to the small scale fishermen and the designing of cages to be done taking into consideration its stability in water current, durability and the ease of management.

Species Selection

Species selection needs to be a well thought-out decision.For any commercial aquaculture there has to be a market for the fish. The fish species should be suited to the local climate extremes and/or should be native to the area. It is essential that established and reliable rearing techniques are known and readily accessible for the intended species or can be obtained by professional consulting and advice. The natural life cycle of the intended fish should be considered so that its basic biological needs can be met e.g. some species can tolerate varying degrees of salinity; some tolerate crowding; some wean onto artificial diets more easily than others do. Some of desirable biological characteristics of species are fast growth and higher yields in different types of culture, efficient conversion of food, tolerance limits of salinity, temperature and oxygen tension, ready acceptance of compounded feeds, good table quality, disease resistance breeding habits; feeding habits and geographic distribution, ease of breeding in captivity, early maturation, high fecundity. Seabass (*Lates calcarifer*), grouper (*Epinephelus* sp.), Rabbitfish (*Siganus* sp.) and Snapper (*Lutjanus* sp.) are the major finfish species suitable cage culture in India.

Cage fabrication for estuarine cages

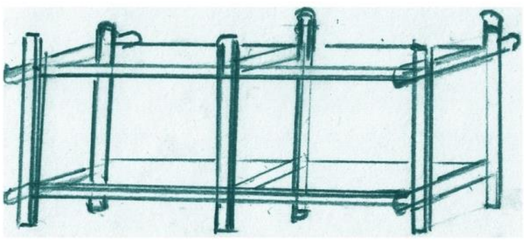
The success of cage culture depends on the rigidity and stability of cages and its popularisation depends on its affordability and ease in operation and the production from it. Over the years various models of cages were designed and fabricated for the use in the estuaries.

Designing of low cost cages affordable for small scale fishermen in Karnataka

Cage designs for culturing seabass, snapper, pearl spot and carangids which can be reared in the estuaries of Karnataka was designed as per the above said criteria. Modifications according to the depths of the water, water currents, tidal influx, bottom structure, easiness of operation, economic viability as well as availability of the quality and dimensions of commercially available fabrication material etc. were experimented. By these studies research team from CMFRI Mangalore could come out with designs of estuarine cages to suit all the estuaries of Karnataka with suggested modification in difference river systems and saline creeks. These models can be adopted almost all creeks along south west coast of India.

After several modifications the cage structure was made to suit the estuaries of Karnataka. Cage model was well accepted in areas where it was tested, as it was found to be with little wastage of GI pipes compared to 4m length model. The GI pipes are sold with a standard size of

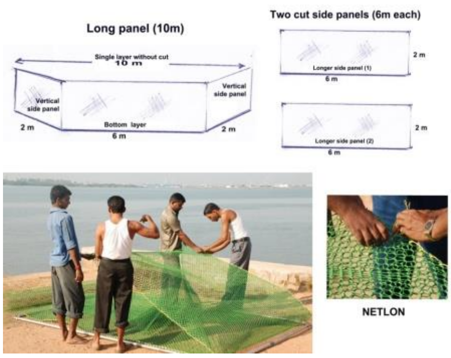
CAGE FRAME 6M x 2Mx 2M



(TOTAL 60 METERS = 1O BARS OF 6 M LENGTH)
guage 1.5 inch

Inner net

18 feet and in order to avoid wastage of material, the length of the cage was extended to 6m, with a dimension of 6m x 2m x 2m. This has a water holding capacity of approximately 24 tons. Higher density GI pipes and one or two middle support was found to be essential for 6 meter cages to keep the stability and shape. The structure of the cage is as given below.



Floatation

Cage mooring:

Successful mooring of the cages is the key for the cage culture. The mooring should be according to the depth, substratum and the current speed. Cage can be slided down to estuary with help of iron rode or wooden logs for easy transferring to water surface. This will reduce man power requirement and also avoid damage with abrasion and change in shape. Nylone ropes are used for mooring rope and in estuaries sand bags are used to provide necessary support to keep the cage in position. Generally sand bags are given in two points, where the shore is too close an additional mooring is also given to avoid the cage touching the shore.

Stocking Density in cages and Feeding

The stocking density is about 50 nos/ cage and in this cage about 1200 nos could be stocked. The red snapper and seabass are stocked in theses cages. The seabass is procured from RGCA hatchery along west coast and the redsnapper is from collection from the wild. The fishes are fed with low value fishes. Upto the 100g size the fishes are fed with 6-8 % body weight and after that it is reduced to 4-5 % body weight. The fishes could be fed adlibitum in cages.

Grow out and production from estuarine cages

The growout is for 10 months or 20 months depending on whether it is possible to tide over the monsoon season. The seabass after 10 months of growth attained about 900-1.2 kg while the red snapper 800-900 kg. The seabass after 20 months of grow out the weight attained was from 3-4 kgs. The production economics is given below.

Expenses:

Cage construction	Rs.
GI pipe frames (6m) 1.5 inch dia. higher gauge 10 bars	10,000
Netlon material for outer cover 25 m roll	7,000
Inner net (12 kg)	5,000
Ropes	5,000
Fabrication and mooring cost	8,000
Floats	5,000
Total construction cost	40,000
(Structure last for 5 years)	
Seed cost @ 15 Rs/ no for 7cm seed (from Hatcheries from TN)	1,80,000
Transportation charges	20,000
Total expenses for 12000 seeds	2, 00,000
Feed cost @ Rs.20/kg low value fish fish/ fish cutting waste 10,000kg	2,00,000
Maintenance cost	1,00,000
Total expenses	5,40,000

<u>Production</u>

1	Cage dimension	6m X 2m X 2m	6m X 2M X 2M
2	Species cultured	Red snapper and seabass	Red snapper and seabass
3	Suggested stocking	1200 nos./per	1200 nos./per cage

	density	cage	
4	Culture period	20 months	10 months
5	Survival expected	80% (app.1000 nos.)	90%
6	Average weight expected	3.0 kg.	1.2 kg.
7	Total production per cage	3,000 kg	1,320 kg
8	Average price /kg	Rs. 450/-	Rs. 450/-
9	Total revenue expected	15.75 lakhs	5.832 lakhs

The cage culture which began in small scale in Uppunda estuary has proved to be successful. The result has encouraged the fishermen to take up this as an alternate livelihood along the coast which resulted in horizontal expansion of the cage culture. Now the farming is taking place in various estuaries along the coast of Karnataka. With a total of five cages in 2008, it has increased to nearly 500 cages in 2017 along the coast.

12. Marine Spatial Planning for Aquaculture Development

A.P.Dineshbabu and Sujitha Thomas
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Fishery Science and fishery technology contributed immensely in augmenting fish production globally and in most of the countries aquaculture production exceeded the fishery production from the wild. With advancement in the allied technologies, the technological support for aquaculture which were concentrated in fresh water species got extended to mariculture also. Indian mariculture which was restricted to bivalve farming in limited parts of the coast, had entered a new vista of development with cage culture of finfishes and shellfishes all along Indian coast by the beginning of 21st century. Feasibility of cage culture practices was demonstrated all along Indian coast by Central Marine Fisheries Research Institute. These demonstrations attracted developmental agencies and stake holders towards this innovative venture. Getting encouragement from the demonstration of high growth of finfishes in cages, small scale cage culture techniques also got popularity among the fishermen living around saline creeks and estuaries. The growing interest among entrepreneurs and the readiness for the financial and technical support by various developmental agencies has open up optimistic future for mariculture development in India. Cage culture of fin fishes and lobsters in sea and estuaries, rack and raft culture of bivalves, pen culture of finfishes and shellfishes are going to be major activities being expected under mariculture.

Zoning, through GIS technology or other methods, is a first step in implementing policies which promote sustainable development. It is by identifying areas which are environmentally suitable and excluding from development, those which conflict with the elements of sustainable development. Haphazard development of aquaculture inevitably leads to environmental overload, conflict among user groups and serious economic losses to the industry. GIS technology gives the planner and developer the capacity to evaluate the interaction of a wide range of environmental and social factors which affect the potential of a region for aquaculture development. This complex of influences is integrated through a ranking and scoring system. Each factor is scored and mapped accordingly. The product of ranks are scores which identify zones where sustainable aquaculture can be developed. The FAO Code of Good Practice for Aquaculture (Annex 8.3) also reflects concepts of sustainability. If these elements and their core values are accepted as the basis for sustainable development, then aquaculture development planning should incorporate them.

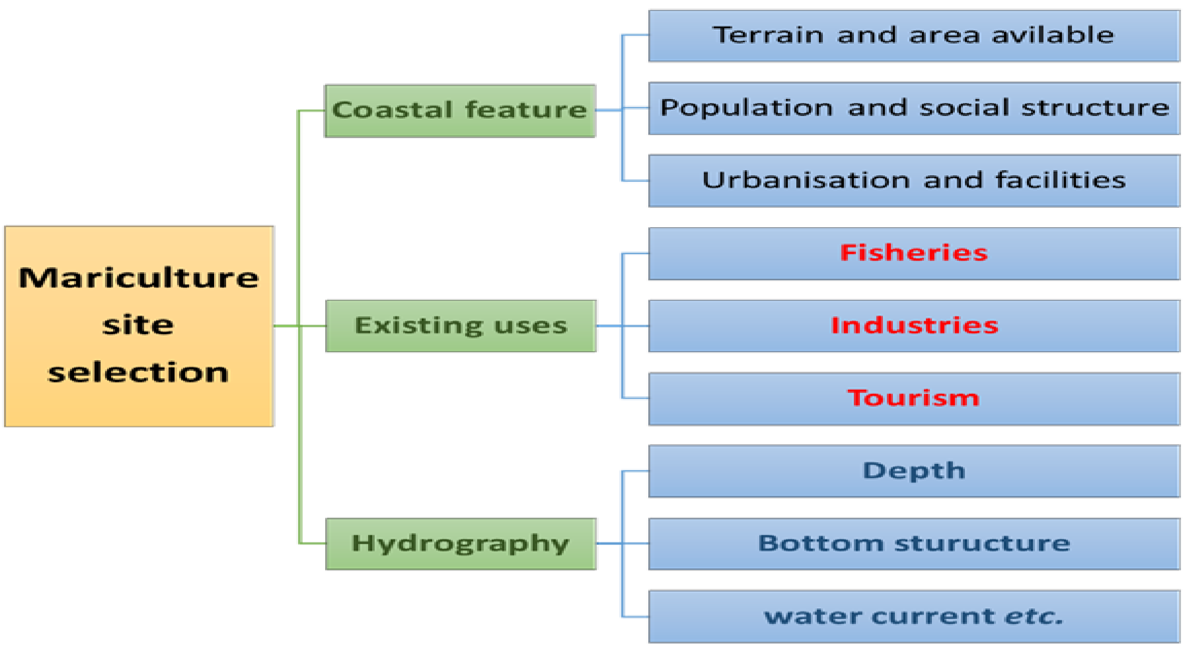
It is now widely recognized that the future of the aquaculture industry will be assured only if it is based on practices which ensure its sustainability. Five elements of sustainable development were given by Muir (1996), citing Jacobs, *et al.* (1987):

- Integration of conservation and development,
- Satisfaction of basic human needs,
- Achievement of equity and social justice,
- Provision for social self-determination and cultural diversity, and
- Maintenance of ecological integrity.

Spatial planning will help

1. To understand present status of usage of coastal waters: GIS based inventory of fishing, industrial, tourism, transport, shipping, oil exploration related activities along west coast of India will be prepared for the purpose to reduce the user level conflicts.
2. To identify areas available for mariculture activities usingMulti-criteria decision analysis.
3. To identify suitable areas for mariculture taking into consideration of physical, chemical, hydrographic, biological social and legal structure from the available water bodies.
4. To identify the suitable technology for selected site, like Open sea mariculture, molluscan culture coastal small scale cages etc.
5. To find out the carrying capacity of selected sites according to the technology suggested.
6. Suggest optimum number of units like cages and rafts in each selected sites to sustain the production from these waters.

7. GIS based modelling of mariculture activities with collected information, to make the development in mariculture eco-friendly and free from conflicts.
8. Derive GIS based spatial planning for aquaculture development and propose action plan to the government to have a regulatory system for the sustainable mariculture development in India.
9. Methodology of Multi-criteria decision analysis used for the mariculture site selection taking into consideration of the multi-user scenario in coastal waters is illustrated below.



Aquaculture development can be directed to suitable areas through a permitting process such as the Scoping Committees at the national and State levels. The developer and financial institutions can evaluate the feasibility of projects more readily. Since the open waters are the common property in India, any mariculture development activity should be well planned by taking care of the utilization of the common waters. The areas suitable for mariculture activities should be identified by taking care of general utilization of common waters, with minimum disturbance to the ongoing activities. The activities suitable for each geographic area have to be identified and the carrying capacity of all these selected areas should be identified. The site can be identified for bivalve farming, sea farming of finfishes and shellfishes and also estuarine farming. The estimation of carrying capacity will help in suggesting how many number of rafts, racks, cages can be put in the particular ecosystem/area without disturbing the natural environment. In case of cage culture the species to be selected, number of cages to be installed, the stocking density and the extend of distribution of waste from cages without causing pollution are the major concern to make the production sustainable. Efficient management and strict regulations are required for the sustainable development. There are many instances in agriculture like that in shrimp farming were the lack of proper management has adversely effected the farming.

Geographic Information Systems (GIS), remote sensing and mapping have a role to play in all geographic and spatial aspects of the development and management of marine aquaculture. GIS based spatial planning gives us the projection scenarios of various physical and biological parameters and will help the scientists to come out with suggestions on species suitability for cages, carrying capacity of the water body, stocking density of the cages and the best feeding strategies and feeding schedules incorporating all chemical, biological and physical features. GIS projections are capable to resolve conflicts for space and resources between stake holders and also to understand the social acceptability and the economic implications of mariculture. A legally viable licensing system and water leasing must be developed and put into practice during the initial development stage itself to avoid any future conflicts among the different stakeholders. GIS based spatial planning is a new concept in Indian mariculture, but it is considered as a major tool in aquaculture development around the world. Food and Agriculture Organisation compiled the use of GIS based spatial planning in aquaculture . These are the list of project listed by FAP GIS in 2007. By 2012 it is reported that there are 391 project which were using GIS based marine spatial planning for aquaculture development in the world (FAO (2012).

Spatial planning is a decision support project to support decision making in mariculture development in India sustainable with eco-friendly and human friendly technologies and selection of Site. The development in mariculture at present is disadvantaged by lack of clear policies on the protection of culture structures in common property like Indian seas. The result s from this project will give a illustrative policy decision support to support and regulate sustainable mariculture development in the country. The Ministry of Agriculture in 2014 has stressed the importance of ‘ blue growth’(aquaculture) in sustainable food production and that this sector is confronted with serious inadequacies of planning, and management. In light of this, this project is relevant and essential for proper planning and management of mariculture activity in the country. The projecr result will fill the lacuna od decision support system in supporting and financing the fishermen who are interested to venture into mariculture.

Indian mariculture which was restricted to bivalve farming in limited parts of the coast, had entered in new vista of development with cage culture of finfishes and shellfishes all along Indian coast by the beginning of 21st century. Feasibility of cage culture practices demonstrated all along Indian e coast by Central marine Fisheries Research Institute. These demonstrations attracted developmental agencies and stake holders towards this innovative venture. Getting encouragement from the demonstration of high growth of finfishes in cages, small scale cage culture techniques also got popularity among the fishermen living around saline creeks and estuaries. High market demand for the sea food in domestic and international market as health food also acted as a catalyzing factor in for this resurgence interest in mariculture activities. The growing interest among entrepreneurs and the readiness for the financial and technical support by various developmental agencies has open up optimistic future for mariculture development in India. Cage culture of fin fishes and lobsters in sea and estuaries, rack and raft culture of bivalves, pen culture of finfishes, and shellfishes are going to be major activities being expected under mariculture. Since the open waters are the common property in India, any mariculture development activity should be well planned by taking care of the utilization of the common waters. The areas suitable for mariculture activities should be identified by taking care of general utilization of common waters, with minimum disturbance to the ongoing activities. The activities suitable for each geographic area have to be identified and the carrying capacity of all these selected areas should be identified. Estimating the carrying capacity of the mariculture is very important in suggesting what kind of culture is possible in the specified area. The site can be identified for bivalve farming, sea farming of finfishes and shellfishes and also estuarine farming. The estimation of varying capacity will help in suggesting how many numbers of rafts, racks, cages can be put in the particular ecosystem/area without disturbing the natural environment. The decision support in sustainable development will lead to fast development of mariculture in the country.

13. Regulatory frame work and policy support for coastal aquaculture

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Globally potential of aquaculture for food production were widely recognized and legal policies drafted in many countries. The development and management of aquaculture is likely to fall within the scope of various pieces of legislation and the expertise of various institutions. Aquaculture activities need to be carefully monitored and controlled because of the numerous interests involved, the diversity of natural resources used the variety of institutions concerned, involvement of a wider range of stakeholders from both public and private sectors. FAO insist that "9.1.1 States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture" (Code of Conduct for Responsible Fisheries (CCRF), Article 9).

Although enriched with vast natural resources and numerous potential species, the sea farming practices have not picked up in the country, perhaps due to the lack of a policy for usage of open water bodies. The coastal areas of the country are densely populated and their major occupation is related to fishing and ancillary activities. Therefore, demarcation of suitable areas for a relatively new venture such as mariculture may invite multi user conflicts. Therefore, to initiate such projects, it is very important to involve the local community and frame suitable policy for aquaculture. Coastal Aquaculture in the open waters requires statutory support and the Government is yet to take major policy decision in this regard. Therefore, any major effort for commercialization of the technology for mariculture of various species will depend on an effective policy framework.

Since the open waters are the common property in India, any mariculture development activity should be well planned by taking care of the utilization of the common waters. The areas suitable for mariculture activities should be identified by taking care of general utilization of common waters, with minimum disturbance to the ongoing activities. In Indian marine scenario, multiple nature of organisations (table blow) make the regulatory system more complex for which need of Marine Spatial planning also made into use.

Organization	**Responsibilities**
Ministry of Environment and Forests	Management of resources in the coastal water
Ministry of Earth Sciences	Scientific monitoring of the marine environment, management of resources in the high seas
Ministry of Agriculture	Development of fisheries, aquaculture, fish processing

Ministry of Water Resources	Erosion
Ministry of Surface Transport	Ports, shipping etc.
Ministry of Petroleum and Natural Gas	Offshore installation, coastal refineries, pipelines etc.
Ministry of Tourism	Tourism activities in coastal regions
Ministry of mines	Mining activities in coastal regions

Registration of open water body farms

During the last decade several estuaries and backwaters in Kerala with high saline conditions have been used for bivalve farming. There are no environmental assessments made either prior to farming and after farming. Studies conducted by the Central Marine Fisheries Research Institute (CMFRI), Kochi have indicated that farming bivalve at the same site for more than three years can negatively impact the sediment structure and benthic faunal communities. These aquaculture activities are conducted in open waters where there are other common users, to legally recognize mariculture has become inevitable. Most nations where mariculture has advanced as a commercial activity, government leasing determines the appropriate areas for mariculture activity, allocating the rights to use the resource and evaluation of environmental impacts.

Monitoring and Administering Agencies

The monitoring process envisaged in this policy frame work should necessarily vest with a research institute. The administering mechanism for the mariculture policy should primarily be vested with the respective state fisheries departments (SFD). The chain of command should begin with the SFDs and end with the local governing bodies. There should be considerable synergy between monitoring and administering agencies for sustainable mariculture development in the country.

Existing legal instruments which have a linkage on estuarine cage farming

Central aquaculture Authority act, 2005

Coastal aquaculture Authority is instituted for regulating the activities connected with the coastal aquaculture in coastal areas.

(a) "coastal aquaculture" means culturing, under controlled conditions in ponds, pens,
enclosures or otherwise, in coastal areas, of shrimp, prawn, fish or any other aquatic life in saline or brackish water; but does not include fresh water aquaculture;

(b) no coastal aquaculture shall be carried on in creeks, rivers and backwaters within the Coastal Regulation Zone declared for the time being under the Environment (Protection) Act, 1986:

Provided that nothing in this sub-section shall apply in the case of a coastal aquaculture farm which is in existence on the appointed day and to the non-commercial and experimental coastal aquaculture farms operated or proposed to be operated by any research institute of the Government or funded by the Government

Provided further that the Authority may, for the purposes of providing exemption under the first proviso, review from time to time the existence and activities of the coastal aquaculture farms and the provisions of this section shall apply on coastal aquaculture farms in view of such review.

Power of Authority to Make Regulations**.-**(1) The Authority may, by notification in the Official Gazette, make regulations not inconsistent with the provisions of this Act and the rules made there under to carry out the purposes of this Act.

As seen in the coastal aquaculture authority act, many of the clauses are not supporting the cage farming and some of them are totally against any farming in brackish water,

Initiative to help fishermen community from the State governments:

Since fisheries in coastal waters is State subject, State government have power to make act for utilising the water resources in best possible away. Some States have taken a progressive steps in those direction and the most important effort in this

The kerala inland fisheries and aquaculture act 2010 is an important legislation passed by Kerala Assembly with the aim of sustainable development, management, conservation, propagation, protection, exploitation and utilisation of the inland fishery sector in the State. This act aims to promote social fisheries and to regulate and control responsible aquaculture activities. It also ensures protection of livelihood and traditional rights of fishermen, the availability of nutritious fish and food security to the people and management of inland fisheries sector of the state. This act can be effectively implemented with the help of relevant rules and regulations to develop and sustainably exploit the inland aquatic resources of the State. A scientific management strategy taking into consideration the economic and social factors affecting the multiple stake holders of the resource is essential. The implementation of the

The Kerala Inland Fisheries and Aquaculture Act, 2010

Translation in English of Malayalam version of the act was published under the authority of the Governor.

An Act to codify and amend the laws relating to inland fishery sector and to provide for the sustainable development, management, conservation, propagation, protection, exploitation and utilisation of the inland fishery sector in the State and for promoting social fisheries and to regulate and control responsible aquaculture activities and to ensure protection of livelihood and traditional rights of fishermen and to ensure the availability of nutritious fish and food security to the people and for matters connected therewith or incidental thereto.

CHAPTER I, PRELIMINARY

(b) 'Aquaculture' means growing any aquatic animals or plants by collecting and

conserving them naturally or artificially in restricted circumstances in any private or public water body or in any aquatic environment and includes cage culture, pen culture running water fish culture, ornamental fish farming, fish farming in reservoirs;

(x) 'public water body' means any water body or transformable area including estuaries

or backwaters or rivers or lakes, ponds or tanks or canals including irrigation canals or reservoirs or check dams or streams vested with the Government or Local Self Government Institutions under section 218 of the Kerala Municipality Act, 1994 or under section 208 (a) of the Kerala Panchayat Raj Act, 1994 or onward by Boards or any other Government – Quasi Government Institutions or organisations;

CHAPTER II

DEVELOPMENT, PROPAGATION, CONSERVATION, MANAGEMENT

(3) Notwithstanding anything contained in any other law for the time being in force, any activity to transform public water bodies from their original state in a manner which would affect fishery activities prejudicially shall be undertaken after consultation with the Fisheries Department in the manner as may be prescribed.

4. Notifying as aquaculture area – (1) The Government may, for the aquaculture related development or for the public interest of aquaculture sector, by notification in the Gazette, declare any public water body or other suitable area as aquaculture area exclusively for aquaculture related activities;

Provided that the provisions under sub-section (1) shall not be applicable to the areas included in the coastal area as defined in the Coastal Aquaculture Authority Act, 2005 (Central Act 24 of 2005).

Provided further that for declaring water bodies or areas as aquaculture area under subsection

(1), decision shall be taken after consulting with the concerned Local Self Government Institutions.

CHAPTER III

AQUACULTURE

8. Restriction on aquaculture activities –

(c) the minimum size or weight below which no fish or any species of fish as specified shall be caught or stocked or sold;

(f) fish farming without considering the carrying capacity of inland water sources indiscriminately.

CHAPTER IV

REGISTRATION AND GRANT OF LICENCE

(2) No person shall engage in aquaculture or filtration in inland water bodies except with a certificate of registration obtained in accordance with the provisions of this Act and the Rulesmade thereunder.

12. *Registration of fishing vessel, fixed gear, free net, aquaculture, hatchery, filtration,etc.*

(1) Subject to the provisions of this Act and the Rules made there under, any owner of a fishing vessel or fixed gear or free net and any person intending to engage in aquaculture, conduct of hatchery or filtration shall submit an application for registration to the authorisedofficer of the place under whose jurisdiction the fishing vessel or free net or fixed' gear is to be used or

aquaculture, conduct of hatchery or filtration is to be undertaken.

CHAPTER V

PROTECTED FISH SANCTUARIES

28. Declaration as Fish Sanctuary(1) The State Government, on the basis of the recommendation of the Technical Committee appointed in this behalf may, by notification in the Gazette, declare any public water body to be a protected fish sanctuary if they consider that such an area is having fishery related or zoologically or naturally or ecologically sufficient importance in protecting and propagating fish or its environment, provided that, if any water body under the possession of Local Self Government Institutions or Government or quasi Government Institutions. Boards or Organisations is situated in the said area, the Government shall, before making the declaration in such area consult the concerned Local Self Government Institutions or Government or quasi Government Institutions, Boards or Organisations.

FINANCIAL SUPPORT

Probable schemes available which can be made suited for estuarine fishermen: There are many financial schemes available to support coastal aquaculture. Since estuarine cage farming is a new innovation in open waters, most of the eligibility condition defined by funding agencies are as such is not applicable for estuarine cage farming. But many of them can be modified to suit to support estuarine cage farming by interaction with funding agencies. Mariculture assistance is at present mainly meant for open sea mariculture. By experiencing the success possibility in small scale cages in estuaries, the fisheries officials can convince NFDB for funding estuarine farming activities.

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List of officials participated in training programme

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