Site selection and water quality in mariculture

D. Prema
Senior Scientist
Central Marine Fisheries Research Institute
Post Box No. 1603, Cochin - 682 018,
Kerala, India
premadicar@gmail.com

Introduction

Mariculture is the cultivation and harvesting (or farming) of fish, shellfish and other aquatic species, including seaweeds, utilising seawater as a growing medium. Site selection and water quality in mariculture is one of the most important factors that determine production and mortality. Choice of site for mariculture is of supreme importance since it affects water quality and influences the economic viability. Many problems affecting the culture as well as the environment can be evaded by proper site selection. Mariculture includes culture of various marine organisms and the present document looks into, site selection and water quality aspects for culture of marine fish, shrimp, bivalves and seaweeds only.

Marine fish

Historically, culture of marine species has been done in situ in coastal waters. Due to increased coastal developments, clean water and suitable sites for coastal aquaculture are lesser. Open sea culture is a major avenue for expansion of culture of marine fish. Offshore culture of marine fish is usually practiced in cages. For cage aquaculture, the site can be in open sea, estuarine or backwater.

Criteria for selecting a site for marine cage culture

Environmental Criteria

Depth

A depth of 6– 10 m at low tide may be considered as ideal condition. Cages should be in sufficient depth to maximize the exchange of water, yet keep the cage bottom well above the substrate (sea floor) in order to avoid interaction between the cage bottom and sea floor. Shallow bays with limited depth of water under cages are not favorable for water renewal. It can cause chemical and bacterial interactions, net damage and predation of the fish by crab and bottom organisms.

Wind and waves

The wind can determine the suitability of a particular site or area for cage fish culture through its influence on cage structures and caged stock. Areas of violent storms are to be avoided. But, effects due to moderate winds can be profitable since it helps the mixing of water. Maximum permissible wind velocity limit is 10 knots for floating cage.

Wave size is determined by wind velocity, wind duration and the distance of open, unobstructed water across which the wind blows; and also by the waves present when the wind starts to blow. At the windward end, waves are poorly developed with small wave heights and short periods of oscillation. However, waves develop with distance, reaching maximum size when they attain the same velocity as the wind. Wave height increases with wind velocity and wave energy increases proportionally with square of wave height. The maximum limit of wave height for floating cages is 1m.

Currents and tide

Good water exchange through cage is essential both for replenishment of oxygen and removal of waste metabolites. A weak and continuous current stream is favorable to bring oxygen and remove wastes in a cage. However excessive currents impose additional dynamic loadings damaging cages, reduce the cage usable volume due to the deformations of the net and may adversely affect fish behavior. The limits for current velocity is with a minimum of 0.05 m S-1 to a maximum of 1 m S-1. In all except a few coastal regions of the world, tidal currents form the predominant source of surface water currents. Attractive forces exerted by the moon and sun on the Earth produce tidal waves. The crest and trough of the wave are termed high and low tide respectively, while the wave height is referred to as the tidal range. Associated with the rise and fall of the tide are the horizontal motions of water or tidal currents. Maximum current velocity occur at the middle of the rise (flood) and fall (ebb) ie., during the mid time between highest and lowest tide. For marine cage culture, tidal amplitude of < 1 m is preferred. Current velocity during monsoon is mainly influenced by littoral current, strong winds, wave effects and increased river discharge. Hence there is every chance that current velocity can exceed its permissible maximum limit prescribed for marine cage culture during monsoon. Monsoon season is therefore generally avoided for marine cage culture activity.

Substrate and bottom dynamics

The sea bottom floor ranges from rocky to soft mud. This bottom floor is the cage site substrate. Mud or rock bottom may cause difficulties for a safe and reliable anchorage for cage. A sandy or gravel bottom is generally suitable. It is very important to avoid areas of erosion, transportation or accumulation of oxygen consuming organic material. If the bottom water exchange is small, oxygen deficiency will be higher and this can lead to the formation of hydrogen sulphide (H2S) which at certain concentrations may become lethal.

Carrying capacity

A major consideration in site selection is carrying capacity of the site, ie., the maximum level of production that a site might be expected to sustain. Intensive farming results in production of wastes which can stimulate productivity and alter the water quality. Hence the profitability or even viability is affected.

Water Quality Criteria

Temperature and salinity

Fish and other farmed organisms have no means of controlling body temperature, which changes with that of environment. A rise in temperature increases metabolic rate and causes a concomitant increase in oxygen consumption and activity as well as production of ammonia and carbon dioxide. Salinity is a measure of the amount of dissolved solids present in water and is usually expressed in parts per thousand. Its relevance to mariculture lies principally in its control of osmotic pressure, which greatly affects the ionic balance of aquatic animals. Rapidly fluctuating conditions of temperature and salinities are harmful for marine life culture. Considerable seasonal changes also to be taken care of during the culture period. For most tropical marine life aquaculture, a temperature of 26-28˚C with no abrupt changes is considered as suitable. Preferred salinity range is within 25 – 40 ppt, evading abrupt changes.

Dissolved oxygen (DO)

Dissolved oxygen is required by all higher marine organisms for the production of energy for essential functions such as digestion and assimilation of food, maintenance of osmotic balance and activity. Oxygen requirements vary with species, stage of development, size and also influenced by environmental factors such as temperature. Solubility of oxygen in water declines with increasing temperature and salinity. If the supply of oxygen deviates from the ideal; feeding, food conversion, growth and health can be adversely affected. It is therefore important that good oxygen conditions prevail at a site.

During the day, there is a net production of oxygen, but at night, when photosynthesis stops, the algal community in water becomes a net oxygen consumer. The environmental conditions conducive to blooms usually occur during the warmer months in areas subject to high nutrient influxes. Avoid areas of occasional recurrence of blooms for cage culture. External sources such as sewage discharges and agricultural runoff may be important contributors to blooms. However, a sudden upwelling of nutrient rich water from deeper layers of the water body may also stimulate blooms. Marine sites having good bottom current which disperse settling wastes are desirable. Preferred DO level for marine life culture is > 6 mg l-1.

pH

The pH gives an idea whether the water is acidic (<7) or alkaline (>7). Extremes of pH can damage gill surfaces, leading to death and it affects the toxicity of several common pollutants like ammonia and heavy metals. The pH of sea water usually lies in the range 7.5 – 8.5. The suitable pH for mariculture is from 7.8 to 8.4.

Turbidity / Total suspended solids and Colour / Transparency

Turbidity refers to the decreased ability of water to transmit light. It is caused by suspended particulate matter. The quantity and quality of material suspended in water column at any particular moment is largely determined by water movement, which transports, fractionates and modifies solids. Large, dense particles are more easily settled than small, less dense particles. Suspended solids in a suitable site for net cage culture should not exceed 2 mg l-1. But its effects also depend on the exposure time and current speed. Turbidity and color in water may result from colloidal clay particles, from colloidal or dissolved organic matter or from an abundance of plankton. Secchi disk visibility can be taken as a measure of color / transparency of the water in marine life cage culture. Optimum transparency expressed as Secchi disk visibility for marine culture is < 5 m as yearly mean.

Inorganic nitrogen

The level of ammonia-nitrogen in the water should preferably be less than 0.1 mg l-1. The ammonia nitrogen in water by the decomposition of uneaten food and debris at the bottom, can affect the fish. Normally in coastal area, sewage discharge and industrial pollution are the main sources of higher level of ammonia in seawater. Nitrate (NO3-N) and nitrite (NO2-N) also contribute to the inorganic nitrogen. The total inorganic nitrogen desirable for culture is < 0.1 mg l-1.

Total inorganic phosphorus

Phosphorous is a limiting nutrient needed for the growth of all plants - aquatic plants and algae alike. However, excess concentrations of P can result to algal blooms. The total inorganic phosphorus for marine life culture is < 0.015 mg l-1.

COD (Chemical Oxygen Demand)

The COD of water represents the amount of oxygen required to oxidize all the organic matter, both biodegradable and non biodegradable by a strong chemical oxidant. Preferred Chemical Oxygen Demand for mariculture is < 1 mg l-1.

Chlorine

Both free and combined, residual available chlorine are extremely toxic to fish. The measurable concentrations of chlorine in water for mariculture is < 0.02 mg l-1.

Heavy metals

Originates mainly from anthropogenic industrial pollution. Avoid sites near to industries and effluent discharge outlets if any present. The toxicity of heavy metals is related to the dissolved ionic form of the metal rather than total concentration of the metal. Mercury (Hg) is toxic to both aquatic life and humans. Inorganic form occurs naturally in rocks and soils. It is being transported to the surface water through erosion and weathering. However, higher concentrations can be found in areas near the industries. The most common sources are caustic soda, fossil fuel combustion, paint, pulp and paper, batteries, dental amalgam and bactericides. Mercury remains in its inorganic form (which is less toxic) until the environment becomes favorable, i.e. low pH, low dissolved oxygen, and high organic matter where some of them are converted into methylmercury (the more toxic organic form). Methylmercury tends to accumulate in the fish tissue, thus making the fishes unsafe to eat. The total mercury in water for marine life culture should be <0.05 mg l-1. Lead (Pb) comes from deposition of exhaust from vehicles in the atmosphere, batteries, waste from lead ore mines, lead smelters and sewage discharge. Its toxicity is dependent on pH level, hardness and alkalinity of the water. The toxic effects on fish is increased at lower pH level, low alkalinity and low solubility in hard water. The lead in water for marine life culture should be < 0.1 mg l-1. Copper (Cu) enters the environment naturally through the weathering and solution of copper minerals and from anthropogenic sources. Anthropogenic sources of copper in the environment include corrosion of brass and Cu pipes by acidic waters, industrial effluents and fallout, sewage effluents, and the use of Cu compounds such as CuSO4 as aquatic algicides. Major industrial sources of copper include smelting and refining industries, copper wire mills, electroplating, metal finishing, coal burning, and iron and steel producing industries. Large quantities of Cu can enter surface waters, particularly acidic mine drainage waters, as a result of metallurgical processes and mining operations. The toxicity of Cu to marine organisms in marine and estuarine environments is influenced by physical factors and chemical characteristics of the marine environment. The copper in water for marine life culture should be < 0.02 mg l-1.

Pesticides

Pesticide refers to any chemical used to control unwanted non-pathogenic organisms, including insecticides, acaricides, herbicides, fungicides, algicides and rotenone (used in killing unwanted fish) (Svobodova, 1993). These chemicals are designed to be toxic and persistent, thus it is also of concern in aquaculture. It can affect the quality of the aquaculture product as well as the health of the fish and humans. Pesticide can be split into seven main categories namely, inorganic, organophosphorous, carbamates, derivatives of phenoxyacetic acid, urea, pyridinium, and derivatives of triazine (Dojlido and Best, 1993). Among these, the chlorinated form is of particular concern due to its persistence and tendency to bioaccumulate in fish and shellfish. Some examples are dichlorodiphenyl-trichloro-ethane (DDT), aldrin, dieldrin, heptachlor, and chlordane. The most common sources are agricultural run-offs, effluents from pesticide industries and aquaculture farms. The safe level of DDT group in water for marine life culture should be $< 0.025\ \mu g\ l^{-1}$.

Accessibility: The culture site should be near a shore preferably with a jetty for boat connection with farms and near a good road for land transportation.

3. Shrimp

Environmental Criteria

Shrimp farms should not be located in Mangrove forests. Shrimp farms should not be located in ecologically sensitive areas like marine parks, sanctuaries etc. The nearness of shrimp farms to other land uses may have some negative impacts due to the seepage of water, which will increase the salinisation of land and water resources. So buffer zones should be provided in such areas depending on the soil conditions. Sandy and/porous soils should be avoided. Shrimp farms should not be located on natural flood drains. Water spread area of a farm should not exceed 60% of the total area of the land. Wherever the intake and outfall are in the same creek, overcrowding of the farms should be avoided. The total area of shrimp farms that could be supported by a creek depends on the water flow, tidal amplitude, water retention time, and level of intensification of culture systems. This is defined as the 'carrying capacity' of the particular creek and can be estimated taking all these parameters into account. New farms can be permitted only after an assessment of the carrying capacity of the creek.

Soil quality

Soil is the most important component in a culture system. The quality of soil should be ascertained for pH, permeability, bearing capacity and heavy metal content. Soil with low pH of below 5 and acid-sulfate soils should be avoided. Similarly soils with high concentrations of heavy metals also should be avoided. The soil characteristics suitable for a shrimp culture farm are as follows.

Soil quality	Optimum level
pH	7 – 8
Organic carbon	1.5 - 2.5%
Calcium carbonate	>5%
Available nitrogen	50 -75 mg/100 g soil
Available phosphorus	4 - 6 mg/100 g soil
Electrical conductivity	> 4 mmhos/cm

Generally clayey loam soils are preferred. Sandy soils are seepage prone and will lead to problems of salinisation of adjoining land and water resources. Further, maintenance of a farm in sandy area needs high capital and operational costs. Hence, sandy areas should be avoided.

Water Quality

Availability of good quality water in required quantities is one of the most important prerequisite for sustainable aquaculture. While locating the farm site, careful study should be made on the source of water, quantity of water available during the different seasons and the quality of water. The optimal levels of various water quality parameters required for the best growth and survival of cultured shrimps are presented below.

Water quality parameters	Optimal level
1. Temperature (C)	28 -33
2. Transparency (cm)	25 -45
3. pH	7.5 – 8.5
4. Dissolved oxygen (ppm)	5 – 7
5. Salinity (ppt)	15 – 25
6. Total alkalinity (ppm)	200
7. Dissolved P (ppm)	
9. Nitrite - N (ppm)	< .01
10. Ammonia - N (ppm)	< .01
1 1. Cadmium (ppm)	
12. Chromium (ppm)	< .1
13. Copper (ppm)	<0.025

14. Lead (ppm)	<0.1
15. Mercury (ppm)	< 0.0001
16. Zinc (ppm)	<0.1

Redox-potential

Anaerobic condition can be developed in pond, when input of organic matter exceeds the supply of oxygen needed for decomposition of organic matter. This reducing condition can be measured as the redox potential (Eh). Redox potential indicates whether the water or soil is in reduced condition (Eh with '-' ve value) or oxidized (Eh with '+' ve value) condition. Reduced or anaerobic sediments may occur at the pond bottom of heavily with heavy organic load and poor water circulation. Under anaerobic condition of the pond bottom, reduced substances such as H2S, NH3, CH4 etc. are formed which are toxic to benthic organisms. In shrimp ponds, development of highly reducing conditions at the surface of the pond mud is highly undesirable. Water circulation by water exchange, wind or aeration helps to move water across mud surface and prevent the development of reduced condition. Draining at the centre of pond, as is being practiced by some farmers, is an ideal remedy for the prevention of formation of highly reducing condition during the last phase of culture period. Bottoms should be smoothened and sloped to facilitate draining or organic waste and toxic substances. The redox potential (Eh) of mud should not exceed -200 mV. Hydrogen sulfide can severely affect shrimp growth in pond. H2S is produced by chemical reduction of organic matter that accumulates and forms a thick layer of organic deposits at the bottom. The bottom soil turns black and a rotten smell is discharged if disturbed. High levels of hydrogen sulfide would affect directly demersal or burrowing shrimps such as P. monodon. At levels of 0.1–0.2 ppm in the water, the shrimps appear to lose their equilibrium and die instantly at a concentration of 4 ppm. Using iron oxide (70% ferrous oxide) to treat the bottom soil containing high levels of H2S would not be economical. The cheaper means is by frequent exchange of water to prevent building up of H2S in the pond.

4. Bivalves

Bivalve mariculture is carried out both in coastal and estuarine waters. The success depends largely on proper site selection. Consideration should be given to primary factors (physical, ecological and biological) and secondary factors (risk, economics and legal) that are critical to the species selected. In addition, the site should be suitable to the method or system intended to be practiced.

Temperature

The ideal water temperature for better growth rate of mussel in farm is 25-33˚ C. For edible oyster, the water temperature range is 21 -31˚C.

Water depth

The depth of water column of a location determines the type of culture method to be adopted. For mussel culture method, it can be in the range from 1-15 m at average mean low tide. For culture in the estuarine conditions, even 1 m depth is suitable for horizontal culture of mussels in lesser muddy bottom conditions. For edible oyster culture, sheltered areas with a depth ranging from 2 to 5 m offering protection from waves are desirable. In areas where the mean tide level is <1.5 m, bottom culture on rocks or other materials can be practiced. The most important consideration with regard to water depth is avoiding long exposure periods during the extreme low-tides.

Water current

Bivalve culture sites should not be in the vicinity of strong currents as strong currents usually generate high turbidity and high siltation rates. However, moderate currents (0.17-0.25m/s at flood tide and 0.25-0.35m/s at ebb tide) are needed to provide adequate food supply as well as to carry away the excessive buildup of pseudofaeces and silt in the culture area.

Salinity

Mussels grow well above 20 ppt, but the ideal salinity for rearing is 27-35 ppt. Open coastal areas are usually fully saline with minor seasonal variations. In estuarine areas, decrease in salinity is usually the major and frequent problem, mainly caused by the influx of freshwater from rivers or land runoff during the rainy season. Therefore sites with a high inflow of fresh water are not suitable for the farming of mussels. For edible oyster, the preferred salinity range is 22 – 35 ppt.

Turbidity

The presence of suspended particles above a certain level disrupts the filtering activity of the bivalve, which often remains closed to avoid tissue damage and also due to gill clogging. In addition, low primary productivity is often the case in sites of high turbidity due to the reduced penetration of sunlight in the water column. As a result poor growth results due to reduced feeding time and limited food availability. It is found that water containing a high suspended load of more than 400 mg/1 have harmful effect on the grow-out of mussels. The maximum suspended load tolerable level varies according to species. A practical method for determining the turbidity level is the use of Secchi disc. Sites having a disc reading less than 15 cm are usually considered unsuitable for bivalve culture.

Primary productivity and food organisms

Clear seawater with rich plankton production (17- 40mg chlorophyll l-1,) is considered ideal for mussel culture. The presence of suitable micro algal species is usually not a limiting factor; however, problems do arise when the availability of food is limited. The carrying capacity of a body of water, (ie., the biomass of animals that the algae food it contains can support) can be exceeded by overstocking, leading to reduced growth.

Source of Seed

Bivalve culture needs 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. Transportation itself is not only costly, but usually negatively affects the quality of bivalve seed due to stressful conditions. The mussel (P.viridis) seed can remain without water for about 24 h and hence offers easy transportability.

Substrate and bottom slope

Substrate composition and stability is a major environmental parameter for selection of site suitable to benthic species such as clams. Substrate composition will determine the suitability of an area for a particular species. Oyster bottom culture is limited to areas where the sea floor is firm enough to support some kind of cultch and where siltation is not excessive. The degree of bottom slope is one factor, when the bivalve species is cultured directly on the substrate. Suitable culture beds should have a moderate seaward slope between 5-15 degrees.

Pollution

The sedentary bivalve fauna are 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. Waters with heavy industrial contamination such as trace metals and organic compounds are therefore unsuitable for mussel farming. Further, shellfish from contaminated areas are known to accumulate bacteria and viruses that are pathogenic to human beings.

Harmful algal blooms

Another criterion of deciding the suitability of potential culture site is eliminating the threat of Harmful Algal Blooms. Some coastal waters are known for the appearance of sudden blooms of certain phytoplankton capable of producing highly potent toxins that are harmful to marine fauna and any other animal that feed on them. Unfortunately, it is often difficult to predict if any area is prone to be affected by these toxic blooms, however, during the site selection process, an enquiry of the past history of the HAB in the area is necessary.

European Union (EU) standards to be met for export of mussel products

Parameters in farm site	**Mandatory level**
Temperature	$\pm 2^{\circ}$C from normal sea temperature
pH	7-9
Salinity	2 - 48 ppt
Dissolved oxygen (Saturation	$>$80 %
Suspended solids (mg l-1)	30

Petoleum hydrocarbons	Should not be deposited in the flesh and larvae.
Organo-halogenated substances	Should not exceed harmful levels in shellfish
Faecal coli forms	< 300 in the shellfish & intervalvular liquid

Heavy Metals in tissue: Maximum permissible residual level (ppm)

1	Mercury	1.0
2	Cadmium	3.0
3	Arsenic	75
4	Lead	1.5
5	Tin	250
6	Nickel	80
7	Chromium	12

Pesticides in tissue: Maximum permissible residual level (ppm)

1	BHC	0.3
2	Aldrin	0.3
3	Dieldrin	0.3
4	Endrin	0.3
5	DDT	5

Antibiotics and other Pharmacologically active substances in tissue: Maximum permissible residual level (ppm)

1	Tetracycline	0.1
2	Oxytetracycline	0.1
3	Trimethoprim	0.05
4	Oxolinic acid	0.3

5. Seaweed

As with other aquaculture systems, selection of a suitable site is critically important for a new seaweed farm. The success of Eucheuma farming does not only depend on farming technology, but also to a large extent on the proper selection of the site. Capture fisheries and ornamental fish collecting activities are harmful to seaweed culture by damaging the culture ground, culture facilities as well as the crop itself. The potential site should be free from such conflicting activities. Accessibility to roads, markets and government services and aquaculture services should be considered.

Ecological criteria

Sheltered area and seed availability

A suitable culture site for seaweed is that which is well protected from tidal waves and strong winds that come from the open sea or monsoonal weather conditions. A good site should be a lagoon sited between an island or coral reefs that are bare during low tide covering the area to prevent destruction or disturbance of seaweeds planted. The availability of local stocks of the species to be cultured at the site is a good indicator that the ecological conditions of the site are favourable for the growth and development of the species.

Water movement

Water movement is a key factor that controls or influences the growth of seaweed. It plays an important role in preventing an increase in pH, caused by consumption of carbon dioxide, and in supplying nutrient. It is also important in water aeration, and preventing the rise in water temperature. Water movement caused by currents is considered a better form of water motion than wave. It is more predictable and less destructive. In an ordinary site, a current of about 20 cm/sec is considered suitable for seaweed culture.

Indicator species

The presence of wild stocks of seaweed at the site or in nearby areas is not only a good indicator of ecological suitability of the site, but also eliminates the problem of seed acquisition. The presence of benthic coelenterate is also an indicator to support the suitability of the site for Eucheuma in terms of good water movement, high level of phosphate, silicate, salinity, dissolved oxygen and high transparency. The abundance of soft corals for instance is an indicator of good water movement.

Sea bed

The substratum provides mechanical support or attachment of the seaweeds. Seaweeds have different types of attachment adapted to various types of substrata. Eucheuma prefers sand or sandy loam substratum with a limited amount of other seaweeds. The Eucheuma will not grow well on bottoms covered with seagrasses. The unwanted seaweeds might compete for nutrients or cover the farm-raised Eucheuma resulting in quick deposition of silt on the stems and branches.

A sea bottom with hard coral formations and coral heads is also not a good site for a seaweed farm. It is difficult to secure the stakes and the area is a good habitat for seaweed predator such as rabbit fish, puffer fish and sea urchin.

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