WATER QUALITY ASSESSMENT AND MANAGEMENT IN AQUACULTURE

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Introduction

Aquaculture is a fast-developing industry that supplies a vital source of protein for human consumption. According to the Food and Agriculture Organization (FAO), aquaculture accounts for nearly 50% of the fish consumed globally. Aquaculture is projected to contribute to 53% of global fish production by 2030. For sustainable, healthy and productive fisheries, ensuring good water quality in aquaculture operations is an essential requirement. Poor water quality will eventually end in low profit, low product quality and potential human health risks.

Factors affecting water quality in aquaculture

Several factors/aspects can affect water quality in aquaculture operations

Temperature: Keeping up the most favourable range is important

Temperature is a crucial parameter in aquaculture that affects the growth, reproduction, and overall health of fish concerned. Temperature fluctuations can cause stress and disease in fish, leading to increased mortality and reduced growth rates. It is essential to maintain a stable temperature that is optimal for the specific cultivated species. Tropical fishes prefer 25 -32°C and temperate region fishes prefer 10 - 15°C. Extreme temperatures can lead to mortality.

pH: Keeping up the idyllic range checks stress and disease

Retaining the optimal pH levels in aquaculture is crucial for preventing stress and disease in fish and for better production. Fish are responsive to changes in pH. The pH change can affect their growth, reproduction, and overall health. The recommended pH range for most fish is 6.5 to 8.5. Deviations from this range can cause stress and disease in fish.

Dissolved oxygen: low levels can be lethal

Fish and other aquatic organisms require oxygen to respire, and dissolved oxygen (DO) is a vital water quality parameter in aquaculture. The ideal DO range for most fish species is 5 - 7 $mg1^{-1}$. Low DO can induce stress, disease, and mortality in fish. Hence, maintaining optimal DO levels is essential for the survival and growth of fish.

Nitrogenous compounds: Excess cause toxicity in the environment

Nitrogenous compounds, such as Ammonia-N - N and nitrite-N are major water quality problems in aquaculture. Total ammonia-N (TAN) toxicity is the most significant problem, with toxic levels causing mortality and reduced growth rates in fish. To manage fluctuating nitrogenous compounds, it is important to use proficient filtration systems, maintain proper feeding practices, and carry out routine water exchanges. High levels of Total ammonia-N, nitrite-N, and nitrate-N can be toxic to fish and other aquatic organisms. The toxic concentrations are greater than 0.1 $mg1^{-1}$ for TAN, above 0.5 $mg1^{-1}$ for nitrite-N and above 100 $mg1^{-1}$ for nitrate-N.

Total Suspended Solids (TSS) and Turbidity: Affect water clarity and primary productivity

High levels of total suspended solids and turbidity in aquaculture can reduce light penetration, affecting the growth of aquatic plants and algae (essential energy sources in the aquatic food chain). High levels of total suspended solids can cause a reduction in growth rates and a rise in fish mortality. For managing TSS levels effective filtration systems and reducing sedimentation is necessary.

Mariculture and water quality

Mariculture is the cultivation and harvesting (or farming) of fish, shellfish and other aquatic species utilizing seawater as a growing medium. The environment has a pivotal role in the success of any mariculture activity. Environmental fitness is one of the most significant factors, in determining the type of mariculture appropriate to the site. The aquatic species under cultivation have all their physiological activities in the water – respiration, excretion of waste, feeding, maintaining salt balance and reproduction. Accordingly, water quality is the decisive factor in the success or failure of a mariculture operation. The incessant degradation of water resources due to anthropogenic interventions insists on a guideline in selecting sites for mariculture using water quality as a basis.

Site Selection

The choice of site for mariculture is of utmost importance -it not only affects water quality but also greatly influences the economic viability. Many problems affecting the culture as well as the environment can be overcome by proper site selection.

Resources

Though Mariculture includes the culture of various forms of marine life, the present document looks into, site selection aspects for the culture of marine fish and bivalves.

Marine fish

Usually, the culture of marine fish has been done in coastal waters. Due to increased anthropogenic pressures, clean water for coastal aquaculture is becoming scanty. The use of open sea mariculture in cages is an alternative for the expansion of marine fish culture. For cage aquaculture, the site can be in open sea, estuarine or backwater, as per the availability, accessibility and suitability of clean water.

Environmental Criteria for site selection in marine cage culture

Wind

Wind determines the appropriateness of a particular site or area for cage fish culture through its impact on cage structures and caged stock. Areas of violent storms are to be avoided. But, moderate winds are helpful since it supports the mixing of water. The wind velocity upper limit is 10 knots for the floating cage.

Waves

Wave size is determined by wind velocity, wind duration, and distance of open, unobstructed water across which the wind blows; 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. 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 the square of wave height. The maximum limit of wave height for floating cages is 1m.

Currents and tide

Suitable water exchange is essential both for the revival of oxygen and the elimination of waste metabolites. A weak and continuous current stream brings oxygen and removes wastes in a cage. Extreme currents can damage the cages, reduce the usable volume due to the deformations of the net and may adversely affect fish behaviour. The range for current velocity is from 0.05 m s^{-1} to 1 m s^{-1}. As per the rise and fall of the tide, there are tidal currents. For marine cage culture, the tidal amplitude should be < 1 m. A littoral current is the current running parallel to the beach and generated by the waves striking the shore at an angle. It is better to avoid the monsoon season for marine cage culture activity, as current velocity can exceed its maximum limit during monsoon.

Bottom dynamics

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 (H_2S) which at certain concentrations may become lethal.

Carrying capacity

The carrying capacity of the site is the maximum level of production that a site can continue to sustain. This is of paramount importance, since intensive farming results in the production of wastes which can stimulate primary productivity and alter the water quality. Hence the profitability or even viability is affected.

Bivalves

Bivalve mariculture is done in coastal and estuarine waters, the success of which is governed mostly by proper site and species 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 practised.

Site selection criteria

Temperature

The preferred water temperature range for a better growth rate of mussel and edible oysters on the farm is 25-33 ^{O}C and 21 -31 ^{O}C respectively.

Water depth

The water column depth of a location decides the type of culture method to be adopted. For mussel culture, the range of water depth is 1-15 m at average mean low tide. In estuarine conditions, 1 m depth is sufficient for horizontal culture of mussels in reduced muddy bottom conditions. Edible oyster culture is preferred in sheltered areas with a water depth range of 2 - 5 m offering protection from waves. The bottom culture of oysters on rocks or other materials can be practiced, where the mean tide level is <1.5 m. It is most important to avoid long exposure periods during the extreme low tides.

Water current

Sites selected for bivalve culture should not be in the vicinity of strong currents since strong currents generate high turbidity and high siltation rates. But these sites need moderate currents (0.17-0.25m s^{-1} at flood tide and 0.25-0.35ms^{-1} at ebb tide) to offer adequate food supply and to as to remove too much accumulation of pseudofaeces and silt in the culture area.

Salinity

Salinity above 20 ppt supports the mussels to grow well, but the best salinity range is 27-35 ppt for mussel rearing. Salinity often decreases in estuarine areas, due to the influx of freshwater from rivers or land runoff during the rainy season and this gives rise to problems in mussel culture in such regions. Hence sites with high discharge of fresh water are not congenial for the farming of mussels. The favourable salinity range for edible oysters is 22 – 35 ppt.

Turbidity

The suspended particles in water above a certain level interrupt the filtering activity of the bivalve and can clog its gills so that it remains closed to avoid tissue damage. Low primary productivity is observed in areas of high turbidity due to the reduced penetration of sunlight in the water column. As a consequence of this poor growth is seen owing to reduced feeding time and limited food availability. Water containing highly suspended solids of more than 400 mg1^{-1} is found to be detrimental to the growth of mussels. The tolerable level of maximum limit for suspended solids varies with the species. A Secchi disc reading of less than 15 cmin sites is generally inapt for bivalve culture.

Primary productivity and food organisms

Clear water with rich plankton production (17- 40mg chlorophyll l^{-1},) is considered best for mussel culture. The presence of appropriate microalgal species is ordinarily not a problem in mussel culture. Problems start when there is a constraint in food availability. The carrying capacity of the selected body of water, (ie., the biomass of animals that can be supported by the food algae present in the system) can surpass its limit by overstocking, which will result in reduced growth.

Source of Seed

Nearness to spat or seed source is important in bivalve culture needs while selecting sites. But, if a spat needs relocating from somewhere else, it should be brought to the farm site within a realistic time and cost. Conveyance is not only expensive but also generally affects the quality of bivalve seed adversely, as a result of stressful situations. The mussel (*P.viridis*) seed remains for about 24 hours without water and so offers uncomplicated portability.

Substrate

Substrate composition and stability is the main factor for site selection for the growth of benthic species such as clams. Substrate configuration will govern the fitness of an area for a particular species. Oyster bottom culture is restricted to regions where the sea floor is hard enough to support clutch. There should not be undue siltation.

Bottom slope

When the bivalve species is to be cultured directly on the substrate, the degree of bottom slope is an important parameter for consideration. Apt culture beds should have a reasonable seaward slope between 5-15 degrees.

Pollution

Bivalves are well-known for accumulating trace metals and pollutants. Waters with heavy industrial pollution such as trace metals and organic compounds are consequently inappropriate for mussel farming.

Harmful algal blooms

Eliminate the threat of Harmful Algal Blooms (HAB) by avoiding such areas which are prone to HAB, through local enquiry about their history in the proposed sites. Secondary data on HAB in published literature can also be referred to. In India, site selection criteria, specifically for marine cage culture have been given by Loka *et al*., (2012). Prema (2013) explains the site selection and water quality criteria in detail for selected mariculture resources (marine fish, shrimp, bivalves and seaweeds).

Environmental Impact Assessment

The environmental impact assessment (EIA), is an essential component determining the success of mariculture endeavors. EIA assesses the probable interrelated ecological, socio-economic, cultural and human-health impacts of the proposed endeavour, both beneficial and adverse. EIA before, during and after the mariculture activity helps with the prediction of impacts. The predictions must outline different scenarios, giving the basic assumptions unmistakably. The main purposes of EIA include informing decision-makers and the public on the environmental consequences of the proposed endeavour, identifying alleviation measures to minimize the possible impacts and providing a framework for the follow-up. The EIA process includes different steps such as screening (the context on which EIA is based, whether an EIA is needed and if needed, up to what extent), scoping (making the EIA focused), public consultation (to know the priorities and problems of the relevant stakeholders) and reporting (a detailed assessment, analysis and report of all the important potential impacts against an environmental baseline). Arrive at the acceptable level of impacts of new activities with known or approved standards and critical values.EIA must reflect possible production and management choices making selections among aquaculture and other alternative uses of resources. The impacts should be appraised and environment management plans (EMP) should be prepared. An EMP is a location-specific plan formulated to ensure that the environment is protected in terms of environmental legislation, but at the same time supportive to the optimum production of the resources. The EIA studies taken up in India and elsewhere in marine cage culture and bivalve mariculture up to 2015 have already been reported by Prema (2015).

Ecosystem approach to aquaculture

The environmental assessment process should be raised to an ecosystem approach to aquaculture (EAA) as recommended by the Fisheries and Aquaculture Department of the Food and Agriculture Organization (FAO) of the United Nations (Soto *et al*., 2008). In the EAA, carrying capacity is an important concept for the management of the ecosystem, to outline the physical limits, production limits, ecological limits and social acceptability of the aquaculture venture. These four types of carrying capacity (*viz*. physical, production, ecological and social) must be considered in the final decision for the mariculture activity, the details of which can be accessed through Prema (2015).

Ecosystem analysis research so far undertaken in the Indian context, aimed at national or macro-level environment management plan (EMP) options for coastal ecosystems. However, Padua et al., 2023 focused on deriving micro-level environment management plans and solutions through a participatory approach for selected tail-end ecosystems to support efficient implementation of the same. This in turn will help in the sustainable development of the selected ecological units.

Based on the ecosystem grading using the ecosystem health index (EHI), the following ward-wise responsible activities are suggested for implementation. The aquaculture and allied aspects already present there were also noted and acknowledged in this document along with the suggested responsible activities for eco-friendly living.

Strategy for aquatic environmental management at the micro-level (Ward wise) for Mulavukad Gramma Panchayath

Responsible aquaculture and allied aspects suitable for Mulavukad Gramma Panchayath		
Ward	**Present**	**New Proposal /Area Expansion**
I	Chinese net, Shrimp farming	Fish cage farming, Shrimp farming, Mud crab fattening, Natural fish seed production and Ecotourism
II	Chinese net, Shrimp farming, Natural fish seed production	Chinese net, Fish cage farming, Shrimp farming, Mud crab fattening, Natural fish seed production and Ecotourism with Recreational fishing and Boating possible.
III	Chinese net, Shrimp farming, Fish cage farming	Chinese net, Shrimp farming, Mud crab fattening, and Ecotourism
V	Chinese net, Shrimp farming, Natural fish seed production	Chinese net, Fish cage farming and Eco tourism
VI	Chinese net, Fish cage farming, Natural fish seed production	Chinese net, Fish cage farming, Natural fish seed production, Ecotourism and Duck farming
VII	Chinese net, Shrimp farming	Chinese net, Fish cage farming (Thilapia), Natural fish seed production and Eco tourism
VIII	Chinese net	Chinese net, Fish cage farming, Bivalve farming, Natural fish seed production and Eco tourism
IX	Chinese net	Chinese net, Fish cage farming, Bivalve farming, Natural fish seed production and Eco tourism
XI	Chinese net	Chinese net, Fish cage farming, Bivalve farming, Natural fish seed production and Eco tourism
XIII	Fish cage farming, shrimp farming and natural seed production	Fish cage farming, Shrimp farming, Bivalve farming, Natural fish seed production and Eco-tourism.
XIV	Chinese net, Natural fish seed production, Ecotourism	Chinese net, Fish cage farming, Shrimp farming, Mud crab fattening, Natural fish seed production and Eco tourism
XV	Chinese net, Shrimp farming, Natural fish seed production	Chinese net, Fish cage farming, Shrimp farming, Mud crab fattening, Natural fish seed production and Eco tourism
XVI	Fish cage farming, Shrimp farming, Natural fish seed production	Fish cage farming, Shrimp farming, Mud crab fattening, Natural fish seed production and Eco tourism.

The spatial plan of proposed responsible livelihood options is made into an interactive map as shown below and can be readily accessed from the ICAR CMFRI website (https://www.cmfri.org.in/inf//EMP_Map3/EMP_Map3.html#13/10.0065/76.2553) by the interested stakeholders.

Screenshot of the interactive map of suggested responsible activities

Prediction, prevention and adaptation of environmental impacts in mariculture

Predictive modelling of environmental impacts can be done based on systematic investigation in a particular area during planning and before the establishment of a culture system. Methods of prevention of environmental degradation can be formulated based on these predictive models. After the establishment of the culture system, routine environmental monitoring can indicate whether or not the actual impacts are within the standard limits, and whether the impact is unchanging or is increasing. Suitable interventions can be done to reduce the impacts both in terms of quantity and intensity.

- For prevention and adaptation of environmental impact, approaches like acceptable site selection and aquaculture zoning can be adopted.
- Spatial mapping can be done for potential mariculture sites after identifying such areas.
- Risk assessment of the likely threats during site selection is an important preventive and adaptive measure.
- Weather-related risks also must be considered and arrangements can be made for the necessary protective measures.
    - For example, fish cages can be firmly affixed to the bottom or a holding structure.
    - An increase in water warming and associated low oxygen, possible increase in eutrophication, etc. can be prevented or minimized if deeper sites with better circulation are chosen for the culture.
    - The possibility of disease spread can be curtailed by increasing the minimum distance between farms for aquaculture clusters or zones.

- Implementation of proper risk communication and weather information systems will help in the management of the culture systems.
- Local-level implementation of operational integrated monitoring systems: Such systems can give early warnings and risk communications to stakeholders. This will help them prepare and adoption of better management practices through location-specific planning in facing urgent situations effectively (De Silva and Soto, 2009).

Impacts of extreme events

The frequency of climate-related extreme events is intensifying, impacting the coastal and marine ecosystems, making noteworthy signals on the fishery and aquaculture operations in the affected areas. The ICAR-CMFRI, Kochi has conducted studies on the impact of extreme events in different selected ecosystems and aquaculture production systems in India.

Post-flood water quality assessment in selected estuaries of Kerala

An assessment was done to find out the impacts of the Kerala floods-2018, on the hydrological characteristics of selected coastal/estuarine systems of Kerala, India, during August – September 2018. The sampling sites covered the districts of Malappuram, Thrissur, Ernakulam, Alappuzha and Kollam. The surface waters were sampled to analyze selected water quality indicators using standard protocols and analytical methods (APHA 1998; USEPA, 2006).

Compared to the pre-flood period, in the Vembanad and Ashtamudi Lakes, there was an increased content of nutrients, especially dissolved inorganic nitrogen (DIN). The major share of DIN was from the content of total ammoniacal nitrogen. Ashtamudi Lake had higher Total Suspended Solids (TSS) but Vembanad Lake showed lesser TSS. In both the Lakes, the chlorophyll contents were higher compared to the pre-flood period. A similar trend was seen for nutrients and chlorophyll in the samples collected from the intertidal waters. The nearshore regions off Kochi and off Neendakara also showed increased nutrients, chlorophyll and TSS.

Response to climate extreme events by different biota and their resilience capacity through simulation experiments at ICAR-CMFRI, Kochi

In 2017, the resilience capacity of six commercially important resources (juvenile/ adult stage) was studied; juveniles of two commercially important finfishes, *Etroplussuratensis* (pearl spot) and *Trachinotusblochii* (silver pompano), post-larvae of the shrimp: *Penaeusmonodon* (tiger prawn), and *Villorita cyprinoids* (black clam). Temperature and salinity are some of the main abiotic parameters affecting the survival of marine biota. These change as the intensity of extreme events like floods and droughts. Three different types of short–term experiments simulating probable ecological conditions during extreme events were conducted on selected test species to understand the response to sudden salinity stress and its revival and response to sudden temperature stress and revival.

Relating the results to extreme events

Heavy rainfall-related extreme events could only be endured by juveniles of black clam and pearl spot, and also by post larvae of tiger shrimp. Survival was not possible for juveniles of silver pompano, seed and adult mussels in such extreme conditions. Only juvenile pearl spots and black clams could tolerate drought-like situations or sudden increases in temperature up to 36°C. It was found that post-larvae of tiger shrimp, juvenile silver pompano, and, seed and adult mussels were susceptible to an increase in SST and drought-like situations. Temperature stress can also lead to fin rot diseases in pearl spots, sudden moulting in shrimp larvae and reduce the capacity for byssal thread formation in mussels which can lead to slippage from ropes in mussel farms. Erratic swimming, gasping and starving were also responses to extreme temperature stress.

Advisories to farmers

Based on the behavioral response and survival of the resources, management advisories for reducing crop loss are developed for mariculture which would increase the preparedness of the farmers to face climate change.

- Pearl spot farmers should avoid stocking fish seed during summer months.
- Farmers should take measures to reduce the farm water temperature by better water circulation and providing shade.
- Mussel farmers are advised to stock the seed only after stabilization of salinity at 25ppt and also to provide shades on the racks to avoid temperature stress.
- Harvest the mussel farm within 12 hrs if the salinity in the farm area decreases below 25ppt.
- Harvest should be planned to avoid crop loss if the salinity increases above 35ppt and if the seawater temperature in the farm rises above 34 °C.

How to manage good water quality in aquaculture?

Managing good water quality in aquaculture requires routine monitoring and management of the various parameters that affect it. Regular monitoring and testing of water quality parameters, such as temperature, pH, dissolved oxygen, and nitrogenous compounds, can identify probable problems before they become serious. According to the World Aquaculture Society, monitoring and testing should be conducted at least once a week to ensure the best possible water quality. Proficient filtration systems like biofilters and mechanical filters, can remove excess nutrients, solids, and other contaminants, to improve water quality, reducing the risk of disease outbreaks.

Feeding in excess can cause an increase of nitrogenous compounds in the water, resulting in poor water quality and increasing the threat of disease outbreaks. Hence it is necessary to feed fish properly with the right amount of food based on their needs. Ensure that the uneaten food is removed punctually from the water. Regular water exchanges remove excess nutrients, nitrogenous compounds, and other contaminants from the water. This will give rise to better water quality reducing the risk of disease outbreaks. The recommended water exchanges for most aquaculture systems should be 10-20% per week. Overstocking can bring about poor water quality, stress, and augmented disease susceptibility in fish. It is crucial to retain the proper stocking density based on the fish size and the volume of water in the system. According to the World Aquaculture Society, the recommended stocking density for most fish is between 20 and 30 kg m^{-3}.

Conclusion

Good water quality is a key factor for sustaining fisheries healthy and productive in aquaculture operations. Factors such as temperature, pH, dissolved oxygen, nitrogenous compounds, and total suspended solids can affect water quality and fish health. Regular monitoring and management of these parameters, along with capable filtration systems, proper feeding practices, periodical water exchanges, and sufficient stocking density, can maintain optimal water quality in aquaculture systems. By prioritizing good quality water in use, aquaculture operations can promise the sustainable production of healthy and nourishing fish for human consumption. The participatory approach in environmental management is very relevant in the present level culture systems. For 'environment management', we don't directly 'manage the environment'. It is human behaviour and actions that have an impact on the environment are to be altered with citizen cooperation to achieve environmental sustainability for economic productivity.

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