

Integrated Oyster-Fish Farming for Enhanced Water and Sediment Quality in an Aquaculture System

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Abstract

The filter feeding activities of oysters affect the nutrient removal, enhance water clarity and sediment quality, thereby imparting a potentially significant benefit to the estuarine systems which can have a significant impact on human well-being. This study considered the effect of oysters in improving the water and sediment quality in an integrated fish-oyster aquaculture system. Experiments were carried out from February to November in the Moothakunnam region of the Vembanad lake in the Ernakulam District, Kerala. The study was carried out using four cages (1×1×1m) referred to as treatments, T1, T2, T3 and T4 by integrating fish (*Etroplus suratensis*) and oysters (*Crassostrea madrasensis*) in the ratio of 1:0.3, 1:0.5, 1:0.7 and 1:0 respectively. The physico-chemical characteristics of water and sediment samples were determined and compared between the treatments. The water parameters such as DO, BOD, COD, TSS, TDS, ammonia, orthophosphate and silicate and the sediment parameters, pH, salinity, ORP, TOC, TC and TN varied with different treatments and months. However, the contents of nitrite and nitrate of water showed variation only with respect to months. Integrated culture of fish and oysters (T1, T2 and T3) exhibited lower levels of nutrients and organic matter compared to that of monoculture (T4). More breaking results were obtained from treatment, T2, wherein a stocking ratio of 1:0.5 for fish : oysters is maintained which supports the fact that fish and oysters in appropriate proportions leads to an improvement in production and quality of waters.

Keywords: Oysters, Integrated culture, Physico-chemical characteristics

Introduction

The greatest effect of aquaculture on its surrounding environment is the output of large amounts of wastes in the form of uneaten food, feces, and excretory products [1,2,3]. Increased environmental concern about the rapid expansion of aquaculture systems has increased research into integrated techniques where more than one species are cultured simultaneously, as a means of using the fed waste resource [4,5]. The main concept of integrated systems is to convert the soluble and solid waste products of the main culture

organism (fish or shrimp) into additional valuable products thereby reducing environmental impacts and increasing the sustainability of the farming operation. In such a system, species are cultured through intensification, optimization of production and better control of nutrient flow and uptake [6]. One of the advantages of integrated farming systems is an environmental improvement of installations, as other organisms consume the waste produced by the main culture [7]. The economic potential of a system is also raised through integrated culture while simultaneously lowering environmental impacts [8].

Filter feeding bivalve molluscs are suggested as a good solution for the global food security problem [9]. Bivalves efficiently convert phytoplankton and other nutrients in water into nutritious and high quality animal proteins, with minimal environmental impact. Natural populations of bivalves are known to control phytoplankton blooms, reduce total suspended solids through filter feeding [10,11,12,13] and recycle and remove organic nutrients in the water column [14,15]. Absence of feed cost for on-growing, greater tolerance for crowding, abundance of natural seeds and relative ease of transport, contribute for the expansion of bivalve culture globally [16,17,18, 9].

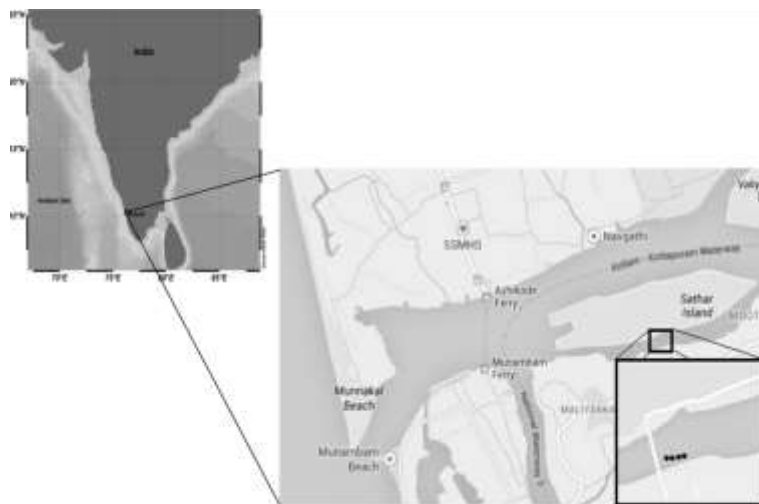
Bivalve aquaculture differs significantly from the culture of most finfish and crustaceans [19,20] in that cultured bivalves exploit naturally occurring phytoplankton at the base of the estuarine food chain, thus obviating the need for external feed inputs. For this reason, shellfish aquaculture does not result in additional nutrient loading, but rather, a transfer of nutrients from water column particles to benthic sediments in biodeposits, rapid nutrient cycling when dissolved inorganic nutrients are released into the overlying water, and a net removal of a portion of those nutrients when shellfish are harvested [21]. The primary purpose of the present study was to evaluate the environmental impacts of oyster farming on water and sediment quality in a cage-fish farming system in a tropical estuary.

1. Material and methods

1.1. Experimental set up

The experiment was carried out in Azhikode estuary in Moothakunnam (10⁰11' N and 76⁰11' E), Ernakulam District, Kerala, India (Figure 1).

Figure 1: Map showing the study area. The four points in the inset shows the position of the four treatments



The experimental setup consisted of four polyethylene cages (T1, T2, T3 and T4) which were laid in the direction of the current maintaining a distance of 50 m between each cage. The treatments were made in

triplicate. The dimensions for each cage was 1×1×1 m. The organisms selected for the study were the pearl spot, *Etroplus suratensis* (Bloch) and Indian backwater oyster, *Crassostrea madrasensis* (Preston). The oyster rens were suspended in the cages. The four treatments differed in the stocking density of the organisms cultured, the details of which are given in Table 1. Fish were fed daily with pelleted feed at the rate of 80-100% of the body weight initially and 5-8% during the last phase of culture. The culture period lasted for 270 days.

Table 1: Details of the experimental set up along with the stocking density (SD) and ratio of fish to oysters in experimental treatments T1 to T4

		T1	T2	T3	T4
Area of the cage (m²)		1	1	1	1
Depth of the cage (m)		1	1	1	1
Organisms cultured		<i>E. suratensis</i> , <i>C.madrasensis</i>	<i>E. suratensis</i> , <i>C.madrasensis</i>	<i>E. suratensis</i> , <i>C.madrasensis</i>	<i>E.suratensis</i>
SD	Fish	100 no. (3-5g)	100 no. (3-5g)	100 no. (3-5g)	100 no. (3-5g)
	Fish:oysters	1:0.33 (by wt.)	1:0.5 (by wt.)	1:0.7 (by wt.)	—

2.2. Sampling protocol

Water samples were collected at monthly intervals for the analysis. For DO and BOD estimations, water samples were collected in labelled DO and BOD bottles (125 ml) respectively. Water samples for other analysis were collected at a depth of approximately 30 cm below the water surface in clean 1 litre polyethylene (PE) bottles. Sediment samples were collected at monthly intervals from beneath the cages in each treatment using a metallic scoop. The collected samples were then transferred to clean plastic bags and transported to the laboratory.

2.3. Field procedures

Values for salinity, temperature and pH were recorded from the field at the time of sampling. Salinity was measured in practical salinity units (psu) using a hand-held Refractometer (Fischer Scientific, model 304). Temperature (°C) was determined using a digital thermometer (OAKTON, USA). A digital pH meter (Eutech Instruments) was used to determine the pH. Water samples for determining dissolved oxygen (DO) were fixed in the field following the modified Winkler method [22]. Rainfall data for the entire period was obtained from the India Meteorological Department-daily weather report for Kerala and Lakshadweep, Trivandrum. Data for the above said parameters are not shown in the paper.

2.4. Laboratory procedures

Water samples were analysed for ammonia, nitrite, nitrate and orthophosphate according to the standard methods [23], and expressed as parts per million (ppm). Water samples were filtered through 47mm GF/C filters and determined with standard spectrophotometric methods. For the analysis of nutrients from the sediment samples, the samples were dried in hot air oven at 50-60⁰C to remove the moisture. The dried sample was ground in a mortar with a pestle and allowed to pass through 0.5 mm sieve. The sieved samples were stored in labelled polythene bags for further analysis. The total organic carbon content of sediment was then determined by the method of El- Wakeel and Riley [24]. An elemental CHN analyzer (Elamantar Vario EL III) was used to determine the total carbon and total nitrogen content of the sediment samples.

2.5. Statistical analysis

Two-way analysis of variance (ANOVA) using SPSS 16.0 was employed to analyze the effects of treatments and month on variations in nutrients. A posteriori, Tukey’s HSD comparisons were applied to determine statistically significant differences at 5% level following ANOVA. Pearson's coefficient of correlation was used to calculate relationships between different parameters.

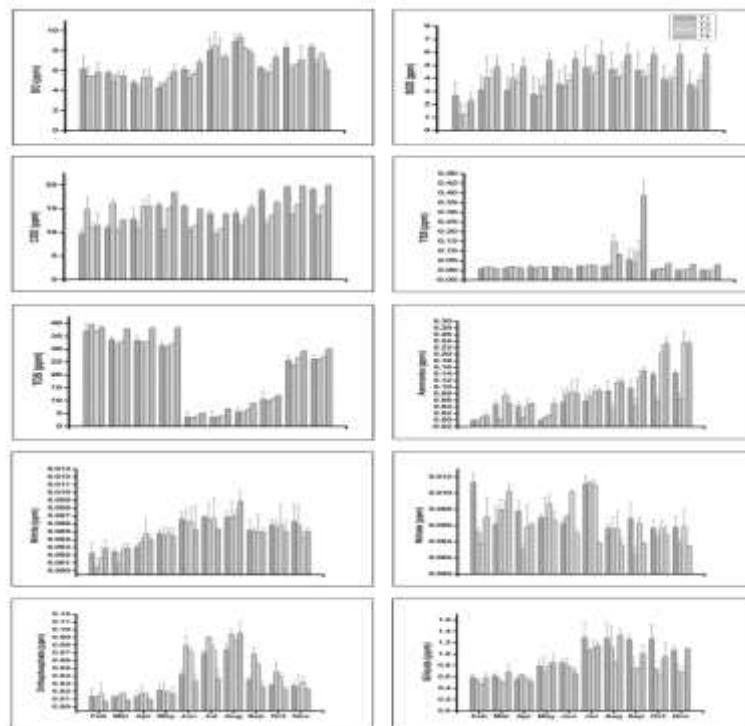
3. Results and Discussion

3.1. Water characteristics

Dissolved nutrients are considered to be the raw material for the marine trophic chain and estuaries are the main entry for nutrients to the marine environment [25, 26]. The increase of nutrient concentrations in estuarine and coastal waters causes a number of environmental modifications, such as increases in productivity, blooms of phytoplankton and decrease of oxygen concentrations and fishery yields [27, 28]. Nutrients are important parameters in the estuaries influencing growth, reproduction and metabolic activities of biotic components. Phytoplankton are filtered from the water column by the oysters and after ingestion and digestion these nutrients are available to support the oyster’s metabolism and growth. Nutrients, nitrogen, and to a lesser amount phosphorus, in the form of dissolved inorganic nitrogen and phosphorus (DIN and DIP) are required to synthesize proteins used to build tissues as the oyster grows. The nutrients, ammonia [NH₃], nitrite [NO₂⁻] and nitrate [NO₃⁻] constitute the dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus is constituted by orthophosphate [PO₄³⁻] [29].

Variation in monthly trends of the nutrients, ammonia, nitrite, nitrate and phosphate is depicted in Figure 2. Among the four treatments, T2 was characterized by lower values of ammonia (0.04± 0.01 ppm) and higher values (0.13±0.03 ppm) were observed in T4.

Figure 2: Monthly variations of ammonia, nitrite, nitrate and orthophosphate of water in the study area.



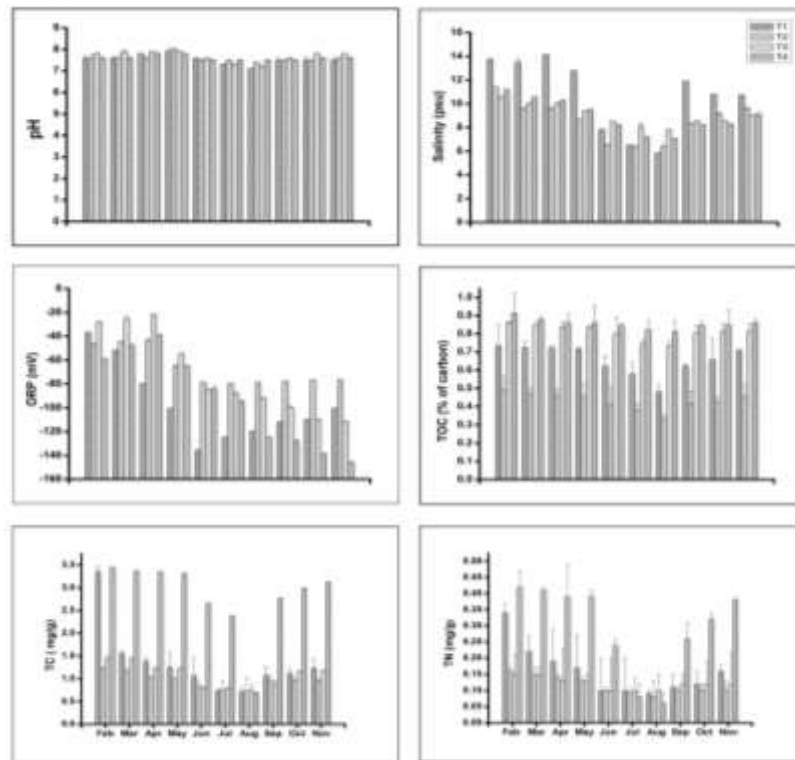
Two-way ANOVA showed significant ($p < 0.05$) differences in ammonia levels with treatments and months. The presence of filter-feeding oysters in T2 stimulates the bacterial process of nitrification and denitrification, helping the escape of nitrogen gas, thus, lowering the ammonia content in water. Newell *et al.* [30] reported in his studies on eastern oysters of Chesapeake Bay that the biodeposits (ammonia) of oysters are oxidized to nitrite and nitrate by aerobic bacteria. The denitrifying bacteria further use the oxidized forms of N as terminal electron acceptors, reducing the NO_2^- and NO_3^- to N_2 gas. Higher values of ammonia were observed in post-monsoon and monsoon which could be due to land run-off, drainage and upwelling of sediments respectively as also observed by Chaudhuri *et al.* [31] in Sunderbans Estuary. A positive correlation of ammonia with COD was observed. An increase in COD causes an increase in DO consumption which inhibits the nitrification process and resulting in increased ammonia content. Nitrite and nitrate values varied from 0.002 to 0.009 ppm and 0.003 to 0.10 ppm respectively. Two way ANOVA showed that there was no significant ($p > 0.05$) variation between treatments, however significant ($p < 0.05$) difference was observed between different months. Peak values of nitrite and nitrate were observed during monsoon which could be due to heavy rainfall, oxidation of ammonia and recycling of nitrogen. Similar findings have also been reported by Das *et al.* [32] in Mahanadi Estuary, Gowda *et al* [33] in Nethravathi Estuary and Rajasegar [34] in Vellar Estuary. Lesser amount of freshwater inflow and higher salinity during the post-monsoon and pre-monsoons lowered the values of nitrite and nitrate in Uppanar backwaters during this period [35]. This is substantiated by the current observation of positive correlation of nutrients with rainfall.

Treatments 1, 2 and 3 were found to be similar in DIP levels (Figure 2) with T2 exhibiting higher levels (0.05 ± 0.01 ppm) and T4 showing lower levels (0.03 ± 0.01 ppm). Two-way ANOVA showed significant ($p < 0.05$) differences between the treatments and months. The removal of phytoplankton by oyster filtration in treatments 1, 2 and 3 probably prevents the assimilation of orthophosphate by the phytoplankton resulting in increased level of DIP. In his studies on eastern oysters of Chesapeake Bay, Newell *et al.* [30] found that bivalve filter feeding sets phytoplankton production at a lower level than that determined by the nutrients. Higher values of orthophosphate were obtained during monsoon months which could be due to the release of phosphates from sediments due to stirring action as observed by Kumar *et al.* [36] in Tapi, West coast of India. A negative correlation of phosphate with temperature was also observed. An increase in temperature leads to increase in the metabolic activities which may cause the active uptake of orthophosphate by phytoplankton. Phosphate was also positively correlated with BOD since an increase in nutrients increases the phytoplankton thereby increasing the O_2 demand.

3.2. Sediment characteristics

The mean values of total organic carbon is shown in Figure 3. All the treatments were found to be different from each other with treatment, T4 showing higher values (0.85 ± 0.03 ppm). Treatment, T2 showed lower values (0.43 ± 0.05) of TOC. All the treatments were found to be different from each other.

Figure 3: Monthly variations of total organic carbon, total carbon and total nitrogen of sediments in the study area.



The mean values for the treatments T1 and T3 were 0.66 ± 0.08 and 0.81 ± 0.04 ppm respectively. This could be due to the absence of oysters in T4 which otherwise would filter out the TOC as shown by [37] in intertidal oyster reef in the South Carolina marsh estuarine system. Maximum values of TOC were observed during the post-monsoon months. Studies [38] have shown that an abundant supply of organic matter in the water column, rapid rate of accumulation of inorganic matter and low O_2 content of the water immediately above the bottom sediments would favour high organic matter in the bottom sediments. TOC exhibited a positive correlation with TC and TN of the sediment. Mineralisation is known to reduce the sediment TC and TN concentrations. Thus as TOC decreases, TC and TN in sediment is lowered and is thus released to the water. Similar conclusions were also reached by Bragadeeswaran *et al.* [39] from Arasalar estuary.

All the treatments were found to be different from each other with respect to the TC content (Figure 3), with T2 exhibiting the lower levels (0.96 ± 0.16 mg g⁻¹). The TC contents for the treatments, T1, T3 and T4 were 1.36 ± 0.75 , 1.08 ± 0.27 and 2.80 ± 0.82 mg g⁻¹ respectively. Lower levels of TC in all treatments as compared to the control, T4, may be attributed to the filter feeding behavior of oysters as they are capable of filtering carbon from the water column as observed in Chesapeake Bay by Cerco and Noel [40]. Among the treatments, T2 exhibited lower levels of TC. The optimum stocking density of oysters in T2 assimilates the TC and there occurs an increase in the fraction of TC lost through respiration. Cerco and Noel [40] have reported that TC deposition is diminished by the introduction of oysters indicating that the minimum computed density is sufficient to reduce the net production of particulate carbon in the water column. They also stated that the carbon removal by filtration levels off as oyster densities increase beyond a certain level.

Total nitrogen (TN) contents of the sediments were found to vary in different treatments (Figure 3). Higher values of TN were found during the non-monsoon periods due to the oxidation of dead plant organic matter, which has settled on the top layer of the bottom [39]. TN was found to be significantly lower in T2 ($0.12 \pm 0.03 \text{ mg g}^{-1}$) because of reduced nitrogen deposition in the presence of oysters. Cerco and Noel [40] have reported that settling of TN decreases because formation of particulate nitrogen in the water column through algal activity is diminished by oyster production. The values of TN for T1, T3 and T4 were 0.16 ± 0.02 , 0.12 ± 0.02 and $0.3 \pm 0.02 \text{ mg g}^{-1}$ respectively. Statistical analysis revealed a positive correlation with ORP of the sediment. A high ORP points to high oxygen content which would result in organic matter mineralisation and production of more TN. Boucher and Rodoni [41] have reported that as the biomass of the oysters increases, the nitrification rate increases, thereby the release of nitrate to water column increases and thus the TN in sediments is found to decrease. This is evident by the negative correlation of TN with the biomass of oysters.

3.3. Nutrient ratios

All the treatments were found to have levels of DIN:DIP and $\text{NO}_3:\text{PO}_4$ ratio much lower than the Redfield ratio. The DIN:DIP ratios for the treatments were 4.19 ± 2.72 , 1.18 ± 0.99 , 3.03 ± 2.24 and 3.67 ± 2.56 ppm for T1, T2, T3 and T4 respectively. The treatments recorded $\text{NO}_3:\text{PO}_4$ values as 0.32 ± 0.24 (T1), (0.20 ± 0.18), 0.23 ± 0.15 (T3) and 0.40 ± 0.41 ppm (T4). This indicates that all the treatments were found to be nitrogen depleted which might be due to the slow regeneration of nitrate compared to phosphate. Similar cases of slow regeneration of nitrate were also observed by Manju *et al.* [42] while studying the water quality parameters along the Kerala coast. The ratio of DIN:DIP and $\text{NO}_3:\text{PO}_4$ exhibited significant difference between different treatments and months. Treatment, T2 recorded the lowest DIN:DIP and $\text{NO}_3:\text{PO}_4$ value. This could be due to the higher values of DIP due to the filter-feeding oysters as demonstrated by Newell *et al.* [30]. As per the observations made by Pollenche [43], phosphorous is mobilized more rapidly from decomposing organic matter than nitrogen and the denitrification process is found to reduce the reactive nitrate pool. And, therefore, this could be the reason for low $\text{NO}_3:\text{PO}_4$ ratios in all the treatments. However, salmon cage farms recorded $\text{NO}_3:\text{PO}_4$ ratio greater than 17 which indicates potential phosphorous limitation [44] in the waters.

At the end of the harvest, maximum harvested yield of 24.55 Kg of fish was obtained from the treatment, T2. The yields achieved from other treatments were 23.2 Kg (T1), 23.83 (T3) Kg and 22.63 Kg (T4). The harvested yield for oysters were 117.05 gm for T1, 200.51 gm for T2 and 57.02 gm for T3. Maximum yield of both fish and oysters were obtained from T2 which again supports the fact that optimum stocking density favours the optimum production of the organisms cultured.

Cage aquaculture has been practiced for years in many countries worldwide, and technology has developed steadily over the last few decades. In Norway, intensive open cage culture with a continuous water exchange [45] has expanded significantly over the last few decades [46]. Cage aquaculture can release considerable amounts of biogenic wastes such as organic wastes and inorganic nutrients that are generated in the production process [45, 47, 48]. The rapid expansion of cage aquaculture has raised concerns about increasing amounts of solid and dissolved nutrients which are released to the aquatic environment [49]. Fish farming releases carbon (C), nitrogen (N) and phosphorus (P) waste into the environment. Dissolved inorganic N (NH_4^+) and P (PO_4^{3-}) (DIN and DIP, respectively) are released through excretion, and inorganic C as CO_2 is released through respiration [50]. These different nutrient components have the potential to influence different parts of the estuarine ecosystem. One of the main challenges facing aquaculture today is sustaining a continued increase in fish production while minimizing the impact on

the environment. The salmon aquaculture industry has taken a number of steps to reduce nutrient release from salmon farming facilities.

Integrated multi-trophic aquaculture (IMTA) is a practical and viable solution for nullifying the possible negative environmental impacts of waste produced by fish aquaculture. It works by exploiting fish waste as a food resource for extractive and filter feeding species at lower trophic levels, thereby also giving an added value to the investment in feed for cage aquaculture [51].

The oysters in the studied IMTA system are known to benefit the ecosystem in three different ways which include alteration of the water quality, alteration of sediment quality and the effect on fish growth. The effect on fish growth could actually be due to the improved water quality offered by the oysters. Oysters are known to affect the nutrient trading process of the ecosystem through the processing of carbon (C), nitrogen (N) and phosphorous (P). The presence of oysters in T1, T2 and T3 lowers the carbon content in the water by their filter-feeding mechanism. CO₂ released from the fish and the faeces is absorbed by the phytoplankton which in turn is removed from the water by oysters. Tang *et al.* [52] studied the effect of shellfish and seaweed mariculture on the removal of Carbon from the ecosystem. Oysters utilize organic carbon through their filter feeding system. Oysters after assimilation, releases a portion of it into water in the form of CO₂ by respiration processes, and some formed bio-deposits through faeces as part of the biogeochemical cycle, a process that accelerates the sedimentation of particles. Treatments, T1, T2 and T3 exhibited lower levels of ammonia when compared to T4 which could be attributed to the presence of oysters. The ammonia released by the pearl spot would probably enter the DIN pool which is taken up by the phytoplankton which in turn is filtered by the oysters in T1, T2 and T3. A portion of ingested N ends up in biodeposits which further through a process of nitrification and de-nitrification releases N₂ gas. The biodeposits of the oysters releases the PO₄ from the sediment probably through microbially mediated reactions. Similar observations were made by Newell and Mann [29] in Chesapeake Bay while summarizing the ecosystem effects of shellfish aquaculture. In their study, they observed that oysters grown in aquaculture floats were able to enhance sedimentary nutrient removal. A portion of the ingested particulate organic nitrogen (PON) and particulate organic phosphorous (POP) from phytoplankton passed the gut of these oysters and ended up as biodeposits. The microbially mediated process of nitrification and de-nitrification caused N to be lost from the biodeposits as N₂ gas and phosphorous to be released from the sediments as PO₄ into the water column.

The study confirms the biofiltration efficiency of *C. madrasensis* and implies that oysters improve water and sediment quality by processing the nutrient cycles in a cage fish culture system by filtering large quantities of particulate matter and nutrients from the water column. Oyster culture had a significant influence on the oxygen and dissolved nitrogen, phosphorous concentrations in the water column suggesting that oyster culture could be used as a positive tool in maintaining sustainability in addition to their primary function of food production in integrated fish-oyster farms. The study also proposes an optimal co-cultivation proportion of fish and oysters in the ratio of 1: 0.5.

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