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Application of Integrated Multi Trophic Aquaculture (IMTA) Concept in Brackishwater Ecosystem: The First Exploratory Trial in the Sundarban, India

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ABSTRACT

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An integrated multi-trophic aquaculture (IMTA) model involving mullets (*Mugil cephalus* and *Liza parsia*) and tiger shrimp (*Penaeus monodon*) as fed-species, and estuarine oyster (*Crassostrea cuttackensis*) and seaweed, *Enteromorpha* spp. as extractive species was evaluated as a viable aquaculture option in brackishwater of the Indian Sundarban. A 150-day field experiment was conducted in six brackishwater ponds (600 m^2 each). There were two randomly assigned groups, IMTA and polyculture (control) with three replicate ponds. Ponds under IMTA were stocked with mullets and tiger shrimp at 10000 and 30000 no./ha, respectively, *C. cuttackensis* at 1600 no./ha suspended with a basket in the water column and *Enteromorpha* spp. at 200 kg biomass/ha. Control ponds were stocked with mullets and shrimp at the same densities to that of IMTA, and devoid of oyster and seaweed. A common low-cost polyculture feed was provided to fishes and shrimp. Mullets attained a significantly higher growth ($p < 0.05$) in the IMTA system compared to that of control ponds, whereas tiger shrimp had insignificantly higher growth in IMTA than in control. Significantly higher production of 1707 kg/ha (19% higher) with better water quality was obtained in IMTA system compared to that of control ponds (1434 kg/ha) ($p < 0.05$). There was a significant reduction in apparent feed conversion ratio by 22%, and an increase in net income by 69% and benefit-cost ratio by 30% in the IMTA system than that of the control. Moreover, for the first time the estuarine oyster, *C. cuttackensis* was used as an extractive species in brackishwater IMTA system. From an indoor trial, it was observed that this oyster species has high water filtration capacity to remove suspended matters, including planktons. This preliminary experiment indicates the application of IMTA concept in brackishwater as a viable environment-friendly option and warrants further refinement for species combination with the economic viability and environmental suitability.

ADDITIONAL INDEX WORDS: *IMTA, polyculture, mullets, tiger shrimp, estuarine oyster, fed-species, extractive species.*

INTRODUCTION

World aquaculture with 110.2 million tonnes of production (FAO, 2018) is growing at a rapid pace caused by modernization and intensification of culture systems. Intensification in aquaculture leads to environmental impact and thereby, the culture system becomes unsustainable. In intensive culture, quite a high amount of inputs in the forms of fertilizers and feeds (50-60% of operational cost) are used to obtain high production in a short period. This results in the deterioration of the culture environment. It was reported that in pond based aquaculture, on an average, only 13% carbon, 29% nitrogen and 16% phosphorus from inputs are retained by cultured shrimp/fish and rest goes to the water and pond sediment (Avnimelech and Ritvo, 2003).

Removal of these accumulated nutrients is a big concern and much cumbersome process. In this context, it could be one of the best options to implement Integrated Multi-Trophic Aquaculture (IMTA) concept for *in situ* removal of organic and inorganic nutrients. In IMTA, two or more aquatic species from different trophic levels are held together in a single production unit as a viable substitute to establish aquaculture more profitable and sustainable (Chopin *et al*., 2001; Muangkeow *et al*., 2007; Zimmermann and New, 2000). The waste of main cultured species or fed species is utilized by un-fed or auxiliary species called extractive species as their energy or nutrient source and growth. Although polyculture is a farming method of multiple species in the same space (Milstein, 2005), from nutrient utilization efficiency point of view, it is a poor performer than IMTA which is a precision aquaculture system. Usually, in polyculture, extractive species are not used. Thus through IMTA, the environmental impact of commercial aquaculture could be mitigated by converting wastes of main

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species into resources for aquatic weeds and filter-feeders to enhance nutrient use efficiency and sustainability of the system (Kumar *et al.*, 2000).

Brackishwater (0.5 to 30 g/l salinity) aquaculture is dominated mostly by a single species, shrimp. Intensive shrimp monoculture may overburden the ecosystem through the release of untreated pond effluents resulting in degradation of the ecosystem. However, more sustainable polyculture in brackishwater ponds involving shrimp, mullets and milkfish is practised by small and marginal producers (Biswas *et al.*, 2012) and requires fewer inputs compared to shrimp culture. However, both these systems need improvement for environmental sustainability. Here is an opportunity to apply the IMTA concept in brackishwater aquaculture. The environmental, yield and economic benefits of IMTA in brackishwater are not clear and warrant investigation. Therefore, the first pond based field trial was conducted in brackishwater eco-system of the Sundarban, India to compare IMTA system with conventional polyculture in terms of environmental impact, production and economic returns.

METHODS

The experiment was conducted for 150 days in the brackishwater farm of Kakdwip Research Centre (KRC) of Central Institute of Brackishwater Aquaculture (CIBA) located at the Sundarban of West Bengal, India. This section presents the experimental design and stocking of species, pre and post-stocking pond management, analysis of water samples, fish performance indices, economic analysis and statistical analysis.

Experimental Design and Species Used

Six rectangular earthen ponds (600 m^2 each) were used. Two culture systems tested in this experiment formed two treatments, namely IMTA and polyculture (control). Each treatment had three replicate ponds which were randomly assigned between treatments. Stocking density of different species in two treatments is presented in Table 1. Among the species stocked, *Mugil cepalus, Liza parsia* and *Penaeus monodon* served as main fed-species, and oyster, *Crassostrea cuttackensis* and seaweed, *Enteromorpha* spp. served as extractive species.

Table 1. *Species combination and stocking density in IMTA and polyculture (control) ponds.*

Species	IMTA (no./ha)	Control (no./ha)
Mugil cephalus	2000	2000
Liza parsia	8000	8000
Penaeus monodon	30000	30000
Crassostrea cuttackensis	1600	—
Enteromorpha spp.	200 kg/ ha	—

Pre-stocking Pond Management

The ponds were dewatered and sundried. Then lime (CaO) was applied to each pond bottom at 500 kg/ha. After 3 days of lime application, ponds were filled with filtered brackishwater drawn through tide from the nearby Creek of Muriganga River to a depth of 50 cm. On day 5, all the ponds were fertilized with mustard cake, urea and single super phosphate (SSP) at 500, 50 and 50 kg/ha, respectively. Ponds were left for 7 days to ensure the growth of natural fish food organisms and the water level was finally increased to 150 cm. Ponds were stocked with farm-raised *M. cephalus* juveniles, *L. parsia* fry collected from nearby estuary and acclimatized to farm condition for 7 days in a pond, and hatchery-produced *P. monodon* post larvae after acclimatization to pond water condition. Oyster, *C. cuttackensis* was collected during low tide from the Hooghly estuarine area where it settled on mangrove plant trunks and concrete pillars of the jetty. After bringing to farm, the oysters were gradually acclimatized to the farm water salinity for 15 days. Oysters were put in perforated plastic baskets and suspended into the water column from a horizontally fixed bamboo pole. Each pond under IMTA treatment had four baskets placed at four different spots. The seaweed, *Enteromorpha* spp. was collected from nearby traditional brackishwater impoundment locally known as *bherry*. Seaweed was kept in a pond for 15 days to acclimatize to farm condition and then distributed to IMTA ponds. A corner of the IMTA pond (10% area) was encircled with ¼ inch net, and seaweed was distributed uniformly there.

Post-stocking Pond Management

A low-cost pellet feed (crude protein: 31% dry matter) was given as supplementary feed at 2-5% body weight per day. The feed composition and feeding strategy were similar to the previously described method (Biswas *et al.*, 2012). However, the feed quantity was adjusted at 15-day intervals based on fish and shrimp body weights calculated from periodical sampling and assumed survival percentage of 100, 90, 80 and 70% in the first, second, third-fourth and fifth month of culture, respectively. To keep water pH within a desirable range, limestone powder was applied fortnightly at 250 kg/ha. Moreover, to maintain sustained desirable water quality in conjunction with optimum natural productivity, mustard cake, urea and SSP were applied at 250, 25 and 25 kg/ha, respectively, at 15-day intervals. Pond water depth was maintained at 150 cm after compensating seepage and evaporation loss of water during high tide at monthly intervals.

Determination of Water Quality Parameters

At 15-day intervals, water temperature, pH, dissolved oxygen (DO), total alkalinity, nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), total ammonia-nitrogen (TAN) and phosphate-phosphorus (PO_4-P) were measured from pond water samples collected between 10:00 and 10:30 h following standard methods (APHA, 1998), and salinity was recorded using a refractometer (ATAGO, Japan). Plankton samples were collected monthly by filtering 50 l of water through bolting silk plankton net (mesh size 64 μm). Plankton concentrates were immediately preserved in 5% buffered formalin for further qualitative and quantitative analysis following direct census method (Jhingran *et al.*, 1969) using a Sedgewick-Rafter counting cell.

Sampling of Stocked Species and their Performance Evaluation

Gravimetric data of fishes and shrimp were collected fortnightly throughout the experimental period from random samples of at least 10% of the stocked quantity. Total length (TL, mm) was recorded with a slide caliper, while body weight

(W, g) was measured using a digital electronic balance. Final Average Body Weight (ABW, g), survival (%) and total biomass produced (kg) were estimated after harvest by drag netting and dewatering the ponds finally. Final ABW of oysters was also computed after harvest and weighing them individually.

Evaluation of Plankton and Chlorophyll Filtration Capacity by the Oyster, *C. cuttackensis*

An indoor trial was conducted in 500 l cylindrical FPR tanks to evaluate filtration capacity of the oyster, *C. cuttackensis* for 96 h. The water of the culture pond was filled in tanks and oysters kept in perforated baskets were suspended into the tank. The tanks were divided randomly into three treatments in triplicate based on oyster biomass density: 0 (control), 0.6 and 1.2 kg/ m^3. Plankton density in tank water was assessed according to the method described earlier at 0, 24, 48, 72 and 96 h. Estimation of chlorophyll-a (Chl-a) pigment in the water of the tanks was carried out at similar intervals as per standard methods (APHA, 1998).

Economic Analysis

An economic analysis to compare IMTA and polyculture (control) treatments was performed with an estimation of the net income, and benefit-cost ratio (BCR) as per the methods described previously (Biswas *et al.*, 2012).

Statistical Analysis

Comparison of fish and shrimp performance parameters, water quality parameters, including plankton density and economic analysis between the two treatments was made with an independent sample *T*-test for equality of means. Differences in plankton density and Chl-a content among treatments of the experiment on plankton and chlorophyll filtration capacity by the oyster were determined by one-way ANOVA followed by Tukey HSD Test for comparison of treatments. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp. All data are expressed as mean ± SEM.

RESULTS

This section comprises of results that include a comparison of water quality parameters, plankton density, fish growth and performance parameters, plankton and chlorophyll filtration capacity by the oyster, *C. cuttackensis* and comparison of economic returns.

Comparison of Water Quality Parameters

Water quality parameters of the experimental ponds are presented in Table 2. Most of the measured parameters differed significantly (p <0.05) between the IMTA and polyculture systems except temperature, salinity and nitrate-nitrogen. In IMTA ponds, mean levels of pH, DO, total alkalinity, NO_2-N, TAN and PO_4-P were significantly low compared to that of control ponds (p <0.05).

Plankton Density in Pond Water

In IMTA ponds, both phyto- and zooplankton densities were lowered from 30 days to the end of the experiment at 150 days compared to the polyculture ponds (Figure 1). Although IMTA ponds had significantly reduced phytoplankton density than in polyculture ponds (p <0.05), zooplankton density in both the systems was similar (p >0.05). About 17 genera of phytoplankton belonging to Bacillariophyceae (8 genera), Chlorophyceae (5) and Myxophyceae (4), and zooplankton belonging to copepoda, rotifera and dinoflagellate were identified from pond water of both the systems.

Table 2. *Physico-chemical characteristics of experimental pond water collected between 10:00–10:30 hours at 15-day intervals from IMTA and polyculture (control) ponds*.

Parameters	IMTA	Control
Temperature (°C)	28.4±0.1	28.7±0.2
pH	8.76±0.07^{a}	8.96±0.02^{b}
Salinity (g/l)	8.08±0.13	7.97±0.12
Dissolved oxygen (mg/l)	5.82±0.42^{a}	5.98±0.53^{b}
Total alkalinity (mg $CaCO_3$/l)	196.89±11.47^{a}	204.37±5.69^{b}
Nitrite-nitrogen (µg/l)	35.99±1.81^{a}	42.29±1.43^{b}
Nitrate-nitrogen (µg/l)	117.22±4.27	118.72±1.07
Ammonia-nitrogen (µg/l)	162.79±13.78^{a}	185.62±11.6^{b}
Phosphate-phosphorus (µg/l)	25.25±1.34^{a}	27.84±1.13^{b}

Values are mean±SEM; Means with different superscripts in a row differ significantly (p <0.05).

Fish Growth and Performance Parameters

Final ABW of fishes and shrimp species was higher in IMTA ponds than in polyculture (Table 3). Although, ABW of *M. cephalus* (439.9±20.7 g) and *L. parsia* (10.8±0.2 g) was significantly (p <0.05) higher in IMTA system compared to that of polyculture ponds, growth of tiger shrimp, *P. monodon* was similar in both the systems. In 5 months, there was a growth increment of about 200 g observed in the oyster of IMTA system. Although pooled survival of fishes and shrimp was similar, total production was significantly higher (p <0.05) in IMTA system (1707 kg/ha) than in polyculture system (1434 kg/ha). Moreover, apparent feed conversion ratio (AFCR) was significantly better (P<0.06) in IMTA ponds compared to that in polyculture ponds.

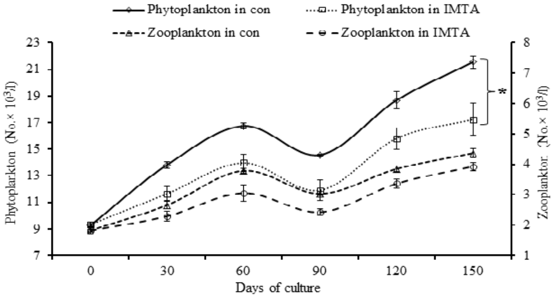

Figure 1. Plankton density of pond water under IMTA and polyculture (con) systems (*p <0.05).

Plankton and Chlorophyll Filtration Capacity by Oyster, *C. cuttackensis*

In 96 h, plankton and Chl-a reduction from water in two treatments (0.6 and 1.2 kg oyster/ m^3) differed significantly from control with no oysters (p <0.05), but not between them (Figures

2, 3). Oysters reduced 38% phytoplankton at 24 h and 74% at 96 h compared to that of control. Zooplankton reduction in treatments was 16% at 24 h and 46% at 96 h in comparison to control. Therefore, 0.6 kg/ m^3 oyster biomass is enough for maximum reduction.

Table 3. *Comparison of final average body weight (ABW), survival, production performance and apparent feed conversion ratio (AFCR) of experimental species between IMTA and polyculture (control) ponds*.

		IMTA	Control
Species	Initial ABW (g)	Final ABW (g)	Final ABW (g)
M. cephalus	149.7±6.5	439.9±20.7^{a}	367.2±9.6^{b}
L. parsia	0.31±0.01	10.8±0.2^{a}	9.23±0.2^{b}
P. monodon	0.14±0.01	35.9±3.1	32.4±3.4
C. cuttackensis	405.2±24.05	633.3±24.1	—
Pooled survival (%)		77.2±2.5	76.2±2.9
Total production (kg/ha)		1707^{a} (Mullets: 926 + shrimp: 781)	1434^{b} (Mullets: 772 + shrimp: 662)
Oyster production (kg/ha)		832.5±45.1	—
AFCR		1.10±0.07^{a}	1.34±0.04^{b}

Values are mean±SEM; Means with different superscripts in a row differ significantly (p <0.05).

Comparison of Economic Returns

A simple economic analysis was performed to estimate the net income and BCR derived from the IMTA and polyculture systems (Table 4). IMTA system significantly outperformed polyculture in terms of total income, net income and BCR ($p < 0.05$).

DISCUSSION

The comparison of IMTA system and polyculture made in this study indicated the feasibility of culturing fish, shrimp, oyster and seaweed together in brackishwater ecosystem. The IMTA model tested here is a simple improvisation of brackishwater polyculture that does not contain extractive species as oyster and seaweed. IMTA model was superior to the polyculture system in terms of environmental impact, yield and economic return.

The water quality parameters improved in IMTA system in comparison to polyculture. However, water quality parameters in both the systems remained stable throughout the experimental period and were within the optimum ranges for brackishwater shrimp and finfish culture (Bhowmik *et al.*, 1992; Biswas *et al.*, 2017; Chakraborti *et al.*, 2002; Jana *et al.*, 2004). Application of lime at fortnight intervals resulted in optimum water quality. As water temperature and salinity were similar in both the systems, differences in cultured species weight gain and total biomass production were probably due to the varied species combinations.

Variation in water temperature and salinity may cause a significant influence on growth in several aquatic species under culture (O'Brien, 1994; Tsuzuki *et al.*, 2000). The observed higher pH conjugated with higher DO contents in polyculture ponds compared to that of the IMTA ponds could be attributed to the maintenance of better aerobic condition in the presence of autotrophic phytoplankton at higher densities in the former system (Azim and Little, 2006). The IMTA treatment was more efficient in the removal of inorganic nitrogenous (NO_2-N, NO_3-N and TAN) and phosphate-phosphorus (PO_4-P) concentrations compared to the polyculture system.

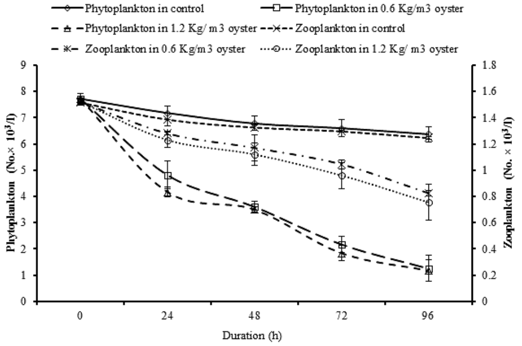

Figure 2. Plankton filtration capacity of the estuarine oyster, *Crassostrea cuttackensis* in 96 h duration. Different letters (a, b for phytoplankton and x, y for zooplankton) at the final values indicate significant differences (p <0.05).

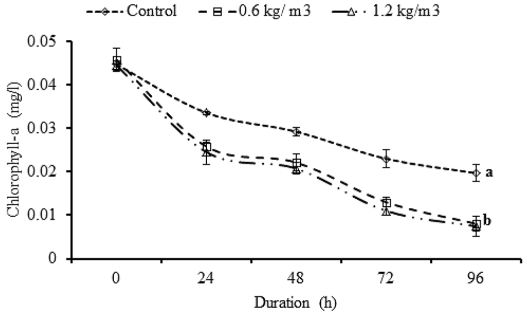

Figure 3. Reduction in chlorophyll-a content of water due to plankton filtration by the estuarine oyster, *Crassostrea cuttackensis* in 96 h duration. Different letters (a, b) at the final values indicate significant differences (p <0.05).

In the presence of phytoplankton, the inorganic extractive macro-algae, *Enteromorpha* spp. used in IMTA utilized the available nitrate and phosphate compounds, and reduced their levels in water (Skriptsova and Miroshnikova, 2011). Moreover, the filter-feeder oyster, *C. cuttackensis* suspended in the water column of IMTA system perhaps reduced the particulate organic matter (Irisarri *et al.*, 2015) which, in turn, caused a reduction in inorganic nutrients.

Concentrations of NO_2-N, NO_3-N, TAN and PO_4-P were higher in polyculture ponds compared to that of IMTA ponds. However, these values were below the desirable limits of 0.25, 0.5, 1.0 and 1.0 mg/l, respectively (Chakraborti *et al.*, 2002), in the polyculture ponds as well.

In the present study, from 30 days onward, both phytoplankton and zooplankton populations were higher in polyculture ponds compared to that of IMTA ponds (Figure 1). More specifically, the phytoplankton population reduced significantly at the end of culture in IMTA ponds than in

Table 4. *A comparison of economic returns between IMTA and polyculture (control) systems.*

	IMTA				Polyculture			
	Expenditure		Income		Expenditure		Income	
	Items	INR#	Items ¥	INR	Items	INR	Items¥	INR
Fish seed*	*M. cephalus*	2000 × 20 =40000	874 × 220 =	192280	2000 × 20 =	40000	727 × 180 =	130860
	L. parsia	8000 × 1 = 8000	52 × 150 =	7800	8000 × 1 =	8000	45 × 130 =	5850
	P. monodon	30000×0.7= 21000	781 × 550 =	429550	30000 × 07 =	21000	662 × 480 =	317760
	Oyster	1600 × 3= 4800	-	-	-	-	-	-
	Enteromorpha	200 × 5 = 1000	-	-	-	-	-	-
Fish feed		114500	-	-	-	113080	-	-
Other inputs		20000	-	-	-	20000	-	-
Manpower		20000	-	-	-	12500	-	-
Total operational cost (OC)		229300	-	-	-	214580	-	-
Interest on OC (@10% annually)		9554			Interest on OC	8941		
Total expenditure		238854	Total income	629630^{a}	Total expenditure	223521	Total income	454470^{b}
Net income : INR 390776^{a}					Net income : INR 230949^{b}			
Benefit-cost ratio (BCR) : 2.64^{a}					BCR : 2.03^{b}			

The calculation was for 1 ha pond and 5 months experimental duration with mean values of each treatment; Means with different superscripts in a row differ significantly ($p < 0.05$).

[*] Mentioned as number of seed × price of each seed.

[#] INR = Indian currency, rupee (100 INR= 1.41 US$).

[¥] Mentioned as total kg of fish/ shrimp × selling price of each kg.

polyculture ponds. This was mainly because of water filtration and removal of sestons and planktons by oysters suspended in the water column of IMTA ponds. Oysters are non-selective filter feeders and known to reduce planktons and suspended particulate matters from water (Nunes *et al*., 2003). It was also evident from the indoor tank trial that the estuarine oyster, *C. cuttackensis* could reduce significantly the planktons and Chl-a content of pond water in 96 h (Figure 2). Both the oyster densities (0.6 and 1.2 kg/ m^3) caused a reduction in plankton density and Chl-a content of water at similar levels. Therefore, it was suggested that *C. cuttackensis* at 0.6 kg/ m^3 is sufficient to clean water and maintain optimum water quality in brackishwater IMTA system where mullets and tiger shrimp are reared as fed species. Similarly, the filter-feeding mussel, *Mytilus edulis* could filter water to remove particulate waste and sestons in a commercial IMTA involving salmon, *Salmo salar* cultured in net-pens (Irisarri *et al*., 2015). Moreover, in a polyculture of Pacific white shrimp, *Litopeneaus vannamei*, giant oyster, *Crassostrea gigus* and black clam, *Chione fluctifraga*, TAN and Chl-a were significantly reduced in the ponds with the highest combined density of molluscs (Martinez-Cordova and Martinez-Porchas, 2006).

The growth and production performances of finfish and tiger shrimp were better in IMTA ponds than in polyculture ponds, indicating the species were in better condition in the former culture system. *M. cephalus* and *L. parsia* had higher weight gain in IMTA system than that of polyculture, whereas, tiger shrimp attained little higher ABW (35.9±3.1 g) in IMTA than in polyculture (32.4±3.4 g) with no significant difference. As the initial ABW of *M. cephalus* was high (149.7±3.4 g), the growth of this species observed in this study was more than in earlier reports on polyculture (Biswas *et al*., 2012; James *et al*., 1985; Shofiquzzoha *et al*., 2001).

However, in an IMTA with seabream, *Sparus aurata* in the tank system, *M. cephalus* attained 42.9-71.9 g from initial ABW of 11.7 g in 284 days (Shpigel *et al*., 2016), which is much lower than that of present IMTA system. Although *L. parsia* showed a better growth (10.8±0.2 g) in IMTA ponds compared to the polyculture ponds, the growth was less than in the previously reported polyculture where it attained 54 g in 180 days (Biswas *et al*., 2012).

Tiger shrimp exhibited similar growth with that of a polyculture comprising of mullets and shrimp that grew 32.79–38.82 g in 195 days (Shofiquzzoha *et al*., 2001). However, the growth of shrimp in this study was better than that of the polyculture with mullets for 180 days (Biswas *et al*., 2012). Pooled survival rates of finfishes and shrimp were similar in IMTA and polyculture systems.

It indicates that both the systems provided similar conducive culture environment to the animals. The total production was significantly higher in the IMTA system than in polyculture, which is attributed to better growth of fishes and shrimp in the former. There was an increase of 19% in total production in IMTA compared to that of polyculture. The production levels in both the systems, were higher than the previous reports of 242.67-294.98 kg/ha in polyculture of *M. cephalus*, *L. parsia*, *Rhinomugil corsula* and *P. monodon* stocked at 1000, 8000, 2000-4000 and 12500-15000/ha, respectively (Shofiquzzoha *et al*., 2001) and 689 kg/ha in polyculture conducted in Sundarban involving *M. cephalus*, *Liza tade*, *L. parsia* and *P. monodon* stocked at 4500, 1500, 2000 and 20000/ha, respectively (Biswas *et al*., 2012). In the IMTA system, AFCR was significantly reduced by 22% compared to the polyculture system. It indicates better feed utilization by the cultured animals in IMTA ponds. Similarly, the IMTA with *S. aurata* and *M. cephalus* reduced FCR by 12-15% compared to their monoculture (Shpigel *et al.*, 2016).

Net income and BCR from both IMTA and polyculture were significantly different with higher net income and BCR in the former system. There were 69 and 30% increase in net income and BCR, respectively in IMTA than that in polyculture. This was mainly because of the increased total production and higher selling price of harvested species due to their higher growth in IMTA system. However, the selling price of harvested oysters was not considered for calculation as oyster has no local market demand. Hence, exploring and establishing a market chain for oyster in metro cities would further strengthen the economic viability of the IMTA model. Similarly, the seaweed, *Enteropmorpha* sp. used here is not an edible one and has less/ no direct commercial importance. However, this species can be a good input for the production of compost manure (Biswas *et al.*, 2017), which could be used in agriculture as well as in aquaculture and thus, some return may be generated for the IMTA model.

CONCLUSIONS

IMTA comprising of mullets, tiger shrimp, oyster and seaweed increased the total production by 19%, reduced AFCR by 22%, increased net income by 69% and BCR by 30% and improved water quality parameters compared to conventional polyculture involving mullets and tiger shrimp. Therefore, the present findings support the environment-friendliness, productivity and economic viability of the IMTA model. There is a scope for economic profitability improvement in this IMTA system by stocking larger size fishes, cultivating edible aquatic weed/ seaweed of commercial value as inorganic extractive species and establishing market chain for the oyster. Further, IMTA as a bio-mitigation solution should become an integral part of coastal regulatory and management models, and be considered as a component for long term planning.

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