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Comparison of mudcrab-based brackishwater polyculture systems with different finfish species combinations in Sundarban, India

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Abstract

To compare production and economic performance of polyculture systems with different species combinations, a 210-day trial was carried out. In the first combination (T1), milkfish (*Chanos chanos*) and mudcrabs (*Scylla serrata*), and in the second (T2), mullets (*Mugil cephalus*, *Liza tade* and *Liza parsia* at 0.5:0.5:0.5 ratio) and mudcrabs were stocked keeping fish and mudcrabs at 15,000 numbers per ha, respectively, in both treatments. The finfish were fed floating pellet at 2%–3% and mudcrabs were fed fresh and farm made feed at 5%–8% body weight. Growth parameters of mudcrabs were similar in both T1 (407.64 ± 105.78 g) and T2 (418.89 ± 105.24 g), with no significant differences. Among finfish, *M. cephalus* attained highest final body weight, 241.55 ± 26.44 g followed by milkfish, 200.46 ± 11.82 g whereas lowest growth noticed in *L. parsia* (63.69 ± 6.62 g). Length–weight analysis of fish indicated negatively allometric growth ($b < 3$) for grey mullets, parsia and milkfish while *L. tade* recorded perfect cube low ($b = 2.99$). Male mudcrabs recorded positive allometric ($b = 3.3$) and female crab exhibited negative allometric growth ($b = 2.68$). The total productivity was 4,533 and 3,694 kg/ha with mudcrab contributes 53.69% and 60.56% to the total productivity in T1 and T2 respectively. The economic analysis indicated benefit–cost ratio (BCR) of 1.57 and 1.73 in T1 and T2 respectively with 10% and 35% insignificant increase ($p > 0.05$) in BCR and profit per kg, respectively, in T2 compared with T1. The study elucidates polyculture of mudcrabs with finfish can be a taken up as a profitable venture for sustainable diversification of brackishwater farming in Sundarbans.

KEYWORDS
C. chanos, *L. parsia*, *L. tade*, *M. cephalus*, polyculture, *S. serrata*

1 | INTRODUCTION

Polyculture is a sustainable farming practice where combination of two or more complementary species, with different feeding habitat effectively utilizes nutrients resulting higher production compared with monoculture (Aubin, Baruthio, Mungkung & Lazard, 2015; Milstein, 2005). In India, traditional brackishwater polyculture practices are age-old and carried out in large tide-fed impoundments known as bheries since 1829 where autostocked fish, shrimp or crabs are reared for a period of 6–7 months with a production up to 500 kg/ha (Lovatelli, 1990). Polyculture plays an important role in nutrient recycling and environmental stability through effective utilization of nutrients derived from the inputs like fertilizers, unconsumed feed, excreta (Aubin et al., 2015; Eldani & Primavera, 1981). In the present scenario of shrimp farming where disease outbreak, environmental issues and market unpredictability are becoming a major challenges, polyculture forms an ideal sustainable alternative to single species monoculture.

Euryhaline fish form an ideal and ecologically important species for polyculture owing to its lowest trophic level feeding habit (El-Dahhar, Nagdy, Amer & Ahmed, 2006; James, 1996; Moriarty, 1976) and ability to accept artificial supplementary diet. Herbivorous finfish such as mullets, *Mugil cephalus*, *Liza tade*, *L. parsia* and milkfish, *Chanos chanos* forms compatible species for polyculture apart from its consumer preference and market price. There are various reports about the polyculture of shrimp with milkfish (Biswas, Ananda Raja, et al., 2012; Eldani & Primavera, 1981; James, 1996; Kuntiyo & Baliao, 1987; Pudadera & Lim, 1982), mullets (Biswas, Ananda Raja, et al., 2012; James, 1996; Shofiquzzoha, Islam, & Ahmed, 2001), tilapia (Tian et al., 2001; Yuan, Yi, Yakupitiyage, Fitzimmons, & Diana, 2010) and bivalves (Hopkins, Hamilton, & Sandifer, 1993; Tian et al., 2001). However, in the last two decades, outbreak of white spot viral disease in shrimp culture demands high biosecurity, with minimum or zerowater exchange farming systems. Thus, culture of shrimp in polyculture farms started losing its popularity in low-lying brackish water areas where tide-fed farming systems are mainly practiced. In these areas, mudcrabs form an economically viable alternative crop for diversification.

Mudcrabs are fastest growing farmed crustaceans (Paterson & Mann, 2011) with an average weekly gain of 10 g per week compared with 2.0 g per week in shrimp (Wickins & Lee, 2002). They are integral part of traditional tide-fed framing across the world (Cowan, 1984). Among the mudcrabs, *Scylla serrata*, *S. olivacea*, *S. tranquebarica* and *S. paramamosain*, the largest and most broadly distributed mudcrab is *S. serrata* (Keenan, 1999; Williams & Primavera, 2001). In India, mainly available mudcrabs are green mudcrab, *S. serrata* and orange mudcrab, *S. olivacea* (Balasubramanian et al., 2014). Though different techniques of mudcrab farming like grow-out culture, crab fattening and soft shell crab production are popular (Anil & Suseelan, 2001; Keenan & Blackshaw, 1999; Trino & Rodriguez, 2002), grow-out culture can yield fully grown crabs which could fetch premium price in export market. However, scientific grow-out crab farming is yet to capture the attention in a larger context due to lengthy culture duration to attain marketable size. Hence, in spite of its tremendous culture scope, it is still considered as a secondary crop to shrimp or fish culture. Mudcrab farming can be highly remunerative when cultured with commercially valuable finishes (Lijauco, Prospero & Rodriguez, 1980; Marichamy & Rajapackiam, 2001; Shelley & Lovatelli, 2012). Recently, it has been reported that polyculture of mudcrab with shrimp and bivalves improve resource utilization, productivity and water quality (Feng, Gao, Dong, Sun & Zhang, 2014) unlike monoculture of crabs where significant amount of nutrients are lost due to feeding habit of mudcrabs (Aubin et al., 2015).

Sundarbans, one of the largest mangrove ecosystems in the world, is inhabited by many commercially important crustaceans. Orange mudcrab, *S. olivacea* is the dominant mudcrab species in this ecosystem. However, culture potential of this species is limited due to its burrowing habit, slow growth rate and early maturity (Kathirvel, Kulasekarapandian & Balasubramanian, 2004). Therefore, efforts were taken to popularize green mudcrab, a non-native species in Sundarbans due to its fast growth rate, less aggressive behaviour and better economic return compared with native ones. Herbivorous fish like *M. cephalus*, *L. parsia* and *L. tade* are part of traditional faming systems of Sundarban, and are much relished for their flesh quality, flavour with good market demand (Biswas, Ananda Raja, et al., 2012; Kalogeropoulos, Nomikos, Chiou, Fragopoulou & Antonopoulou, 2008; Pillay, 1954). Similarly, milkfish, *C. chanos* has been of great demand in Sundarbans. The farmers in Sundarban generally stock mudcrabs and finfish separately which often leads to differential economic success or failures due to risk in monoculture systems. Polyculture has well been regarded as a sustainable and efficient aquaculture system that optimizes the potential of species cultured. Keeping this in view, the present experiment was carried out to compare the performance of two polyculture systems with different species combination for economic viability of mudcrab-polyculture systems.

2 | MATERIAL AND METHODS

2.1 | Pond preparation and stocking

The experiment was carried out for 210 days in the brackishwater farm situated at Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture (CIBA), Kakdwip (21°51′N and 88°11′E), South 24 Parganas, West Bengal, India. Six earthen ponds (100 m^2) were selected for the experiment. Before start of the study, all the ponds were filled with brackishwater from nearby Muriganga River to a depth of 150 cm. On day 1, bleaching powder ($CaOCl_3$) was applied at the rate of 200 kg/ha to disinfect the viral load and unwanted weed fish. On day 10, lime ($CaCO_3$) was applied to all ponds at the rate of 200 kg/ha based on the pond pH. On day 14, ponds were fertilized with urea and triple super phosphate at a dose of 25 kg/ha at 1:1 ratio and left undisturbed for 15 days to allow plankton development. The ponds were stocked with two different species combination. In the first treatment T1, milkfish (*C. chanos*) and mudcrabs (*S. serrata*), and in the second treatment (T2), mullets (*M. cephalus*, *L. tade* and *L. parsia*) and mudcrabs were stocked keeping fish and shrimp at 15,000 numbers per ha, respectively, in both treatments. Each treatment was repeated in triplicate. In detail, in treatment 1 (T1), the ponds were stocked with milk fish fingerlings (40 g) and in treatment 2 (T2), combination of different species of mullets (*M. cephalus* [3.23 ± 0.09 g], *L. tade* [39.67 ± 0.88 g], and *L. parsia* [3.5 ± 0.09 g]) at the ratio 0.5:0.5:0.5 were stocked at 15,000 numbers per ha, respectively, in both treatments. Nursery reared *S. serrata* juveniles (85.4 ± 2.33 g) from Muttukadu Experimental Station of ICAR-Central Institute of Brackishwater Aquaculture, Chennai were also stocked at 15,000 numbers per ha in both the treatment. Hide out (PVC pipes) were provided at 0.1 nos/m^2 to reduce cannibalism among mudcrabs during moulting period.

2.2 | Feed management

The finfish were fed commercial floating feed (crude protein 30%, Godrejj Agrovet Pvt. Ltd) whereas mudcrabs were fed low cost fish meal, molluscan meal and farm made feed. Proximate composition of the commercial fish feed is given in Table 1. The finfish were given commercially available formulated diet at 2%–3% of the biomass whereas mudcrabs were fed at 5%–8% body weight. Farm feed prepared using dry fish meal powder (67%), refined wheat flour (30%), Vit-mineral mix (1%), soya lecithin (1%), cod liver oil (1%) at the pond site was also given. For mudcrabs, 40% of the feed was given in the morning and 60% of the feed was given in the evening. Left-over supplementary feed or unconsumed feed contributed primary productivity which in turn was utilized by herbivorous fish.

2.3 | Water quality analysis

Water samples were collected between 09:00 and 10:00 hours at fortnightly intervals and analysed. Physical parameters like salinity, temperature and pH were measured using an ATAGO hand refractometer (Atago, Japan), thermometer and pH meter (model 10E; Deluxe) respectively. Water quality parameters like dissolved oxygen and alkalinity were determined according to standard procedures (APHA (American Public Health Association), 1998). Water nutrient parameters like total ammonia-N (TAN), nitrite-N (NO_2-N), nitrate-N (NO_3-N) and phosphate-P (PO_4-P) were analysed following the procedures of Strickland and Parsons (1972). For chlorophyll-*a* analysis, water samples were collected monthly and filtered through glass fibre filter (Whatman GF/C) and the collected materials were immediately transferred to centrifuge tubes containing 10 ml of 90% acetone, sealed and stored overnight in a refrigerator. The samples were homogenized with a tissue grinder, and then centrifuged for 10 min at 2,000 *g*. The supernatant was carefully transferred to glass cuvettes (3.5 ml) and absorbance was measured at 750, 664, 647 and 630 nm using a spectrophotometer (model UV2310; Techcomp). Chlorophyll-*a* concentration was calculated using the trichromatic equation given in APHA (American Public Health Association) (1998).

TABLE 1 Proximate composition of the floating finfish feed used for rearing milkfish and mullets in polyculture mudcrab ponds

Proximate	% composition
Crude protein	30
Crude fat	4
Crude fibre	6
Moisture	10
Organic matter[a]	91
Ash	9
NFE[b]	41

Note. [a]Organic matter = 100–Ash %.
[b]Nitrogen-free extract = 100–(Crude protein % + Lipid % + Crude fibre % + Ash % + Moisture).

2.4 | Growth performance and economic analysis

Sampling of mudcrabs and finfish was carried out monthly and the daily feed ration was adjusted, based on the newly estimated biomass for each treatment group. The final survival, productivity and cost of production were calculated from the total harvest. Growth performances and productivity of two treatments were evaluated in terms of final average body weight (ABW), daily weight gain (DWG g/day), percentage weight gain (PWG, %), specific growth rate (SGR, % per day), survival (%), feed conversion ratio (FCR), total productivity (kg/ha) and survival as follows.

$$\text{FCR} = \text{feed applied/live weight gain}$$

$$\text{PWG} = [(\text{mean final weight-mean initial weight})/\text{mean initial weight}] \times 100$$

$$\text{Survival} = (\text{Total number of fish or crab harvested})/\text{Total number fish or crab stocked}) \times 100$$

$$\text{DWG} = (\text{mean final weight-mean initial weight})/\text{rearing duration in days}$$

$$\text{SGR} = [(\text{ln final weight-ln initial weight})/\text{rearing duration in days}] \times 100$$

Economic analysis of the treatments were performed to estimate the net return and benefit–cost ratio (BCR) as follows:

$$\text{Net income} = \text{total income} - \text{total operational cost or total expenditure}$$

$$\text{BCR} = \text{total income/ total operational cost or total expenditure}$$

To understand the length–weight relationship and condition factor, the harvested crabs and finfish were weighed using a digital electronic balance having 0.01 g precision and length was measured with a standard ruler with precision of 0.01 cm. Carapace width (CW) of mudcrabs was taken as the distance between the tips of the last anterior lateral spines and total length of fish was calculated from tip of the mouth to tip of the caudal fin.

The length and weight parameters were subjected to curvilinear regression analysis, using the power function ($W = aL^b$), where W indicates the dependent variable, L the independent variable, a intercept of the regression curve (a constant), and b the regression coefficient (Froese, 2006; Pinheiro & Fransozo, 1993). Prediction accuracy or percent of variability in the regression line was indicated by the coefficient of determination (R^2). Relative condition factor, Kn was used following the equation, Kn = W/aL^b where W = weight in g, L = length in cm (Froese, 2006; Le Cren, 1951).

2.5 | Statistical analysis

Comparison of total productivity, water quality parameters and economic analysis between the treatments were determined by independent sample *t* test for equality of means, and growth performance like DWG (g/day), PWG (%), SGR (% per day) among the different cultured species were analysed through one-way ANOVA using SPSS for Windows v.16.0 programme (SPSS Inc., Chicago, IL, USA). Significance level was determined at 95% probability level.

3 | RESULTS

3.1 | Water quality parameters

Water quality parameters did not show any marked variation between treatments. The salinity and temperature varied between 4.5 and 9.3 ppt and 13–31.5°C, respectively, during the study period. Mean and range of the water quality parameters are given in Table 2. Total ammonia nitrogen (TAN) levels were 342.02 ± 135.80 and 322 ± 123.70 μg/L in T1 and T2, respectively, with no significant difference ($p > 0.05$) between the treatments. The water quality parameters like pH, salinity, alkalinity, nitrite-N (NO_2-N), nitrate-N (NO_3-N) did not vary significantly ($p > 0.05$) between treatments. The levels of Chlorophyll-*a*, an indication of primary productivity status of the ponds were 262.4 ± 40.11 and 253 ± 29.79 μg/L, respectively, in T1 and T2 with no significant difference ($p > 0.05$) between the experimental groups.

3.2 | Growth and production performance

The monthly average growth rate of the finfish and mudcrabs during study period is given in Figure 1. Average weekly gain of *S. serrata* in the present study was 10.73 and 11.13 g with SGR 0.74% and 0.76 g% in T1 and T2 respectively (Table 3). Similarly, grey mullet recorded highest average SGR, 2.43 ± 0.06% per day among the cultured fish and crabs. The DWG of grey mullets *M. cephalus*, 1.33 ± 0.15 g/day was on par with mudcrab, 1.5–1.6 g/day while daily growth gain of *C. chanos* was 0.89 g/day.The lowest DWG was noticed for *L. parsia* (0.33 ± 0.04 g/day). Average final body weight and survival of mudcrabs and finfish are given in Figure 2. Mudcrabs attained an ABW, 407.64 ± 105.78 and 418.89 ± 105.24 g in T1 and T2, respectively, with no significant difference ($p > 0.05$) among the treatments. At the end of experiment, *M. cephalus* attained highest ($p > 0.05$) ABW, 241.55 ± 26.44 g followed by milkfish (200.46 ± 11.82 g), *L. tade* (168.83 ± 4.28 g) and lowest body weight was attained by *L. parsia* (63.69 ± 6.62 g). Among the cultured species, significantly higher ($p < 0.05$) survival was recorded in *C. chanos* (76.88 ± 1.74%) followed by grey mullet, *M. cephalus*, *L. tade* and, mudcrabs recorded lowest survival, 35.6%–39.69%. Total productivity of mudcrab was similar in both the treatments with no significant difference between the treatments. The average total productivity per crop was 4,533 and 3,694 kg/ha with mudcrabs contributions 53.69% and 60.56% to the total productivity, respectively, in milkfish- mudcrab (T1) and mullet-mudcrab (T2) culture ponds respectively (Figure 3). As mudcrabs are highly cannibalistic and have differential growth during culture period, the harvested crabs were grouped in to different size groups based on the weight attained at the end of the culture (Table 4). Among the harvested male crab, 37.27% of mudcrabs belongs to 250–500 g size groups, 21.12% belongs to 500–750 g size groups and 11.2% male mudcrabs attained weight above 750 g size. Among the harvested female mudcrabs, 50.00% and 38.52% crabs belong to 100–250 g and 250–500 g size groups respectively and only 6.76% mudcrabs belong to above 500 g size groups. The production performance of finfish in both systems was not significantly different ($p < 0.05$).

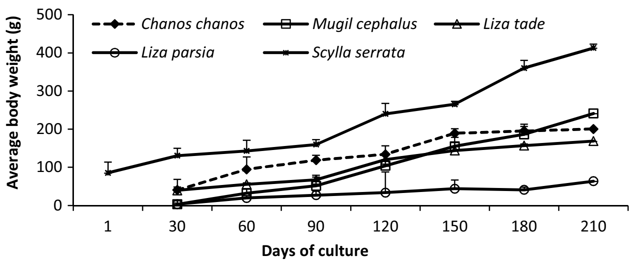

FIGURE 1 Average monthly growth rate of mudcrab *Scylla serrata* and finfishes (*Mugil cephalus*, *Liza tade*, *Liza parsia* and milkfish) in polycultutre ponds (*M* +*SE*)

TABLE 2 Water quality parameters (*M* ± SD) in mudcrab polyculture ponds based on independent student's *t* test

Water quality parameters	T1	T2
pH	8.30 ± 0.40 (7.58–9.0)	8.36 ± 0.4 (7.5– 9.2)
Salinity (ppt)	7.39 ± 1.62 (4.5–9.3)	7.37 ± 1.60 (4.5–9.3)
Alkalinity (mgCO_3)	185.23 ± 24.98 (160–260)	182.87 ± 27.49 (148–260)
Dissolved Oxygen (ppm)	5.6 ± 0.33 (4.9–6.01)	5.62 ± 0.38 (4.8–6.3)
Temperature (°C)	25.59 ± 7.06 (13.3–31.5)	25.48 ± 7.07 (13.0–31.2)
Nitrite-N (μg/L)	35.56 ± 12.94 (8.37–51.39)	31.04 ± 11.79 (8.2–49.13)
Total ammonia-nitrogen (μg/L)	342.02 ± 135.80 (44.9–660.4)	322 ± 123.70 (55.17–652)
Phosphate-P (μg/L P)	25.80 ± 8.83 (10.79–38.36)	24.72 ± 8.89 (11.19–37.45)
Nitrate-N (μg/L)	154.67 ± 24.49 (98.4–190.3)	153.18 ± 24.05 (98.3–191.4)
Chlorophyll *a* (μg/L)	262.40 ± 40.11 (219–354.5)	253.00 ± 29.79 (223.58–313.6)

Ranges are in parenthesis. Means with no superscript letter in common per factor indicate significant difference.

TABLE 3 Daily weight gain percentage weight gain and specific growth rate (*M* ± SE) of mudcrabs and finfish reared in polyculture system based on one-way ANOVA

Growth parameters	*Mugil cephalus*	*Liza tade*	*Liza parsia*	Milk fish	*Scylla serrata* (T1)	*Scylla serrata* (T2)
Daily weight gain (g)	1.33 ± 0.15[c]	0.72 ± 0.02[b]	0.33 ± 0.04[a]	0.89 ± 0.07[b]	1.53 ± 0.03[c]	1.6 ± 0.01[c]
Percentage weight gain (PWG, %)	24,055 ± 2,694[a]	16,783 ± 428[b]	6,269 ± 663[c]	19,946 ± 1,184[b]	40,658 ± 811[a]	41,789 ± 359[a]
Specific growth rate (% per day)	2.43 ± 0.06[a]	0.80 ± 0.02[c]	1.60 ± 0.07[b]	0.89 ± 0.04[c]	0.74 ± 0.01[c]	0.76 ± 0.01[c]

Note. The means with no superscript letter in common per factor indicate significant difference. If the effects were significant, ANOVA was followed by Tukey test.

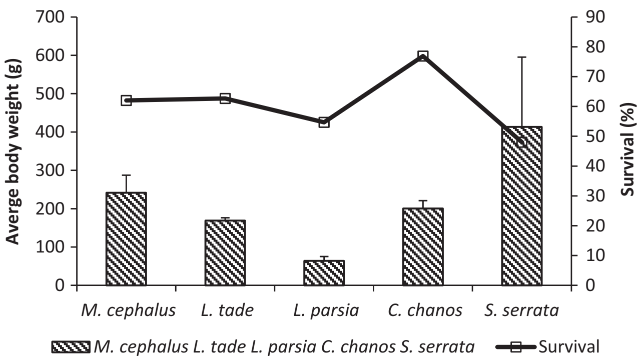

FIGURE 2 Final body weight and survival of finfishes (*Mugil cephalus*, *Liza tade*, *Liza parsia*, *Chanos chanos*) and mudcrab *Scylla serrata* in polycultutre ponds (*M* +*SE*)

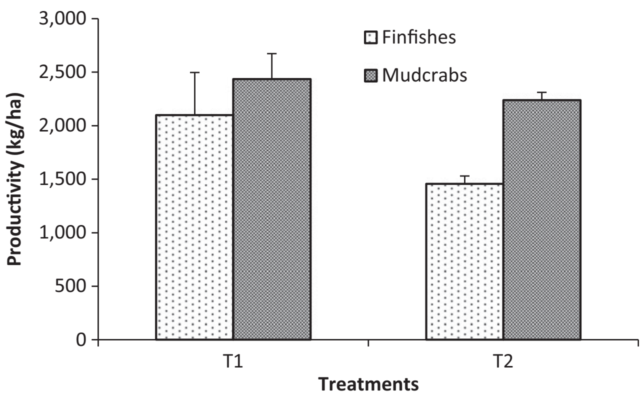

FIGURE 3 Total productivity of milkfish with mudcrab (T1) and mullets (*Mugil cephalus*, *Liza tade*, *Liza parsi*) with mudcrabs (T2) in polycultutre ponds (*M* + *SE*)

TABLE 4 Percentage of different size groups of harvested male and female mudcrabs at the end of the culture

	% wise contribution	
Mudcrab size group (g)	Male	Female
>100	1.86	4.73
100–250	28.57	50.00
250–500	37.27	38.51
500–750	21.12	6.75
750–1,000	4.35	
1,000–1,250	4.35	
1,250–1,500	1.86	
<1,500	0.62	

TABLE 5 Statistics of regression analysis of length–weight relationship analysis of harvested *Chanos chanos*, grey mullet, *Liza tade*, *Liza parsia* and green mudcrab in polyculture system

	Regression parameters			Length		Weight		
Fishes/crabs	*a*	*b*	R^2	Min (cm)	Max (cm)	Min (g)	Max (g)	Sample size, *n*
Milkfish	0.06	2.40	0.68	20	40	70	500	338
Grey mullet	0.07	2.41	0.85	18.3	32	80	320	85
Liza tade	0.01	2.99	0.86	20.5	30.5	58	300	58
Liza parsia	0.17	2.12	0.69	11	25	20	170	34
Green mud crab male	0.09	3.30	0.91	7.2	19.2	60	1,550	161
Green mud crab female	0.33	2.68	0.92	8	18	70	690	157

3.3 | Length–weight analysis and condition factor

The scatter diagram for fish and crabs was obtained by plotting weight against length/CW of individual crabs and fish. The statistics of regression of length–weight relationship is given in Table 5. The regression trend of mudcrabs indicated variation in the growth pattern for male and female mudcrabs. The regression coefficients, b value were 3.30 and 2.68 for male and female mudcrabs respectively. Length–weight analysis of harvested finfish in the regression equation for *M. cephalus* (*b* = 2.41), *C. chanos* (*b* = 2.40) and *L. parsia* (*b* = 2.12) was found to be negatively allometric with b value below 3 whereas *L. tade* followed perfect cube law, *b* = 2.99 with isometric growth pattern.

The mean relative condition factors for finfish are given in Figure 4. Among the harvested finfish, the highest relative condition factor was recorded for *L. parsia* (1.11 ± 0.04) followed by *L .tade* (1.09 ± 0.01), *M. cephalus* (1.05 ± 0.99) and the lowest condition factor recorded for *C. chanos* (0.9 ± 0.01). Relative condition factor analysis indicated that 88%, 78% and 65% of recorded value of relative condition factor of *L. tade*, *M. cephalus* and *L. parsia* lies between 1 and 1.5, respectively, whereas only 24% of harvested milkfish had a relative condition factor above 1.

The sex-based difference on relative condition factor; Kn value for *S. serrata* is given in Figure 5. The average Kn values for male and female mudcrabs were 1.06 ± 0.02 and 1.04 ±0.01, respectively. Relative condition factor analysis indicated that 74.5% of male crabs had a relative condition factor above 1 (1–1.5) whereas only 25.46% of male crabs had condition factor below 1. Out of the harvested female green mudcrab, 51% crabs recorded relative condition factor above 1 (1–3), and 49% recorded below 1. Sex-wise comparison revealed no significant variation between male and female crab, although male crab was found to exhibit higher Kn than female crab. Average relative condition factor between the male and female crabs did not show any significant difference ($p < 0.05$).

3.4 | Economic analysis

A simple economic analysis was performed to estimate the net income and BCR was derived from the two polyculture systems (Table 6). Polyculture ponds with combination of mullet species (T2) outperformed the milkfish treatment system (T1). The economic analysis indicated BCR of 1.57 and 1.74 in T1 and T2, respectively, with 10% and 35% insignificant increase in BCR and profit per kg in mudcrab-mullet system compared with milkfish-mudcrab culture. The average farm gate price for mullets was Rs 200 per kg and milkfish was Rs 120 per kg in West Bengal market. Economic analysis indicated the economic viability of both systems with 57%–74% rate of return over operational investment.

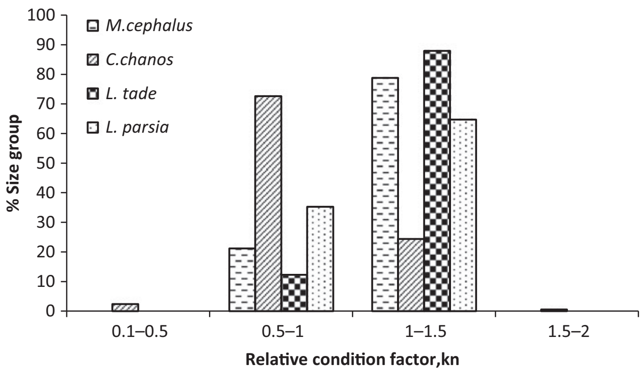

FIGURE 4 Frequency distribution of relative condition factor (Kn) of harvested fishes grey mullet, *Liza tade*, *Liza parsia* and milkfish

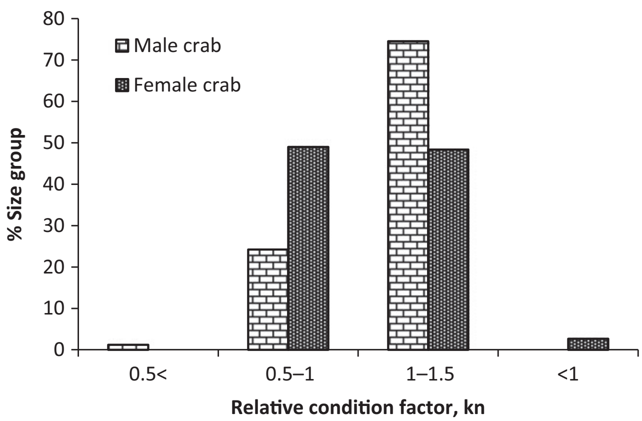

FIGURE 5 Frequency distribution of relative condition factor (Kn) of harvested male and female green mudcrabs

4 | DISCUSSION

Mudcrabs or mangrove crabs are integral component of traditional farms and large extensive bheries in West Bengal, India. Polyculture of mudcrabs with economically important finfish are gaining momentum due to profitability, better environment stability compared with monoculture or crab fattening. The present study was carried out to comprehend the economic feasibility of mudcrabs-based polyculture system in Sundarbans.

The water quality parameters in both T1 and T2 did not vary significantly ($p > 0.05$) (Table 2) and were within the acceptable ranges for brackishwater aquaculture (Anand et al., 2013; Biswas, Ananda Raja, et al., 2012; Chakraborti, Sundaray & Ghoshal, 2002). Application of agricultural lime, $CaCo_3$ at fortnightly intervals helped in maintaining the desirable pH (8.3) and good growth of autotrophic organisms (Azim & Little, 2006). Polyculture systems with multiple species improve recycling of resources to maintain biological and environmental stability (Milstein, 2005). The level of Chlorophyll-*a*, an indication of primary productivity status of the ponds (Table 2) was in accordance with earlier reports on shrimp ponds (Martin, Veran, Guelorget & Pham, 1998). However, the value was higher than fertilization-based nursery finfish ponds (Biswas, De, et al., 2012) and shrimp ponds (Anand et al., 2014). It is reported that fish prefer artificial feed even in the presence of natural food (Luzzana et al., 2005), and in fish culture ponds, nutrients keep on accumulating over the culture period and support good natural productivity. A primary productivity level of 300 mg C/m^3/hr was noticed in polyculture ponds (Biswas, Ananda Raja, et al., 2012). A higher level of chlorophyll a in the present study confirms that the primary productivity in the polyculture ponds was contributed from recycling of unutilized supplementary feed or faecal matter generated in the ponds which in turn enhanced primary productivity and feed for herbivorous fish.

Average weekly gain of *S. serrata* in the present study was 10.73 and 11.13 g with SGR 0.74 and 0.76 g% in T1 and T2 respectively (Table 3). Mean body weight of mudcrabs attained in the current study (407–418 g) was higher than pond-reared monosex crops of mudcrabs (310–400 g), and pen-reared mudcrabs (310–320 g) in mangrove system (Trino, Millamena & Keenan, 1999; Trino & Rodriguez, 2002). Also, the growth rate recorded in the present study was higher compared with earlier reports on mudcrab pond culture (Kathirvel et al., 2004; Linder, 2005; Rahman, Hoq & Ahmed, 2004). Coculture of herbivorous fish in the present study might have helped to maintain optimum water quality characteristics which in turn

TABLE 6 Comparison of economic parameters for mudcrab-milkfish (T1) and mudcrab-mullet (T2) polyculture system based on the operational cost

Items	Amount	Price rate (Rs)	T1	T2
Chanos chanos fingerlings	15,000 per ha	15 per fingerling	225,000	
Grey mullet fry	5,000 per ha	9 per fry		45,000
Liz tade fingerlings	5,000 per ha	20 per fingerling		100,000
Liz parsia fry	5,000 per ha	2 per fry		7,500
Scylla serrata juvenile	15,000 per ha	15 per juvenile	225,000	225,000
Bleaching powder	200 kg	25 per kg	5,000	5,000
Urea	100 kg	10 per kg	1,000	1,000
SSP	100 kg	8 per kg	800	800
Agrilime, LSP	1,000 kg	7 per kg	7,000	7,000
Crab fencing, feeding tray, hide outs, miscellaneous		7,000	7,000	7,000
Labour	100 mandays	270 per mandays	27,000	27,000
Feed mullet (FCR 1.8)	2,477 kg	46 per kg		113,937
Milkfish feed (FCR 2)	3,800 kg	46 per kg	1,74,800	
Crab feed (FCR-3.8)	Mollusc 2,312 kg (T1); 2,125 kg (T2)	120 per kg	2,77,476	255,018
	Fish 6,937 kg T1 + 6,375 kg (T2)	50 per kg	3,46,845	3,18,773
Interest on operation cost 7 Month		12% annually	90,784	77,912
Total operational cost			1,387,705	1,190,940
Cost of production (Rs)			308.30	324.34
Total revenue from crab and fish (Rs)	Milkfish (kg)	120 per kg		2,081,000
	Mullet (kg)	200 per kg	2,199,080	
	Mudcrab (kg)	800 per kg		
Net return			801,530.50	882,888.80
Profit per Kg			177.00	239.00
Benefit–cost ratio (BCR)			1.57	1.74

Calculation was for 1 ha pond and 210 days of experimental duration. Currency mentioned is Indian Rupee (100 INR = 2.05 US$).

might have attributed for better growth. Apart from the supplementary feed, mudcrabs utilizes animal or vegetable matter in the pond bottom as they are opportunistic scavengers (Rodríguez, Triño & Minagawa, 2003; Williams & Primavera, 2001) which also might have imparted better growth rate compared with crabs reared in monoculture.

Among the cultured fish and crabs, significant variation ($p < 0.01$) was noticed for average final body weight, SGR, DWG, etc. Growth rate of grey mullet used in the present study was much higher compared with earlier reports (Biswas, Ananda Raja, et al., 2012; James, 1996; Shofiquzzoha et al., 2001). For example, *M. cephalus* recorded highest average SGR, 2.43 ± 0.06% per day compared with 1.6 g % per day SGR and 92.29 ± 4.36 g body final weight gain reported in 6 month polyculture of mullets with tiger shrimps (Biswas, De, et al., 2012). Higher growth rate of *M. cephalus* recorded in the present study might be due to its opportunistic benthophagous feeding behaviour (Lebreton, Richard, Parlier, Guillou & Blanchard, 2011; Pillay, 1954) which might have fed unutilized feed and detritus biomass generated in the pond. Further, it has been reported that in culture ponds, grey mullet accepts artificial feed even in the presence of natural food organisms (Luzzana et al., 2005; Sarojini, 1954). Their nutritional requirements, therefore, could be met by low cost supplementary feeds (Crosetti & Cataudella, 1995). Moreover, the residues of macrobenthos, fish or molluscan meal fed by mudcrabs also might have served as food for bottom detritus feeder grey mullet compared with plankton feeding milkfish. It is reported that in 5 month culture lesser mullets attained a lower growth rate, 0.28 to 0.35 g DWG and 0.40 to 0.48% per day SGR compared with fast growing *M. cephalus* (Karapanagiotidis et al., 2004). However, in the present study *L. parsia* and *L. tade* recorded better growth performance (Table 3) compared with earlier observation (Biswas, Ananda Raja, et al., 2012; James, 1996; Shofiquzzoha et al., 2001).

Growth rate of milkfish varies with respect to environmental condition. In a 120-day milkfish-tiger shrimp polyculture, milkfish exhibited higher DWG of 1.28–1.65 g/day (Eldani & Primavera, 1981) compared with 0.89 g/day in the present study. Similarly, Guanzon, de Castro-Mallare and Lorque (2004) also reported a higher growth rate of milkfish, 2.47–2.57 g/day when cocultured with red seaweed. According to Jana, Garg and Patra (2006), monoculture of milkfish in inland saline ground water (10 ppt) resulted in a mean body weight of 107 g and 1.1 g/day whereas in

25 ppt the fish attained better growth, 324 g and 3.2 g/day in 100 days culture, suggests that salinity can play an important role in growth rate of fish. Growth rate of milkfish noticed in the present trail was higher than the earlier study (0.7 g/day) in Sundarban where milkfish was cultured with tigers shrimp in tide-fed polyculture system (Biswas, Ananda Raja, et al., 2012), and in previous reports (Gandhi & Mohanraj, 1986; James, 1996). Though, initial weight used in the present study was not similar due to constraints in the availability of different species (fish and crabs) with same initial weight during stocking time, the DWG (g/day), SGR (day %), percentage weight gain (%) were compared to find the difference in growth performance of the species in the present system. It is well known that better growth can be achieved when natural food is supplemented with artificial or supplementary feed. The individual variation in weight may also be due to the different degree of stomach fullness and gonadal maturation of the cultured animal. In the present study, commercial feed was used unlike fertilized system which wholly depends on the plankton in the pond. Studies of Barman and Garg (2003), however, suggested that milkfish require about 40% dietary protein for better growth. Comparatively, lower growth in the present study may, therefore, be attributed either to lower salinity (<10 ppt) and/or to less protein or fat contents in the feed.

Among the cultured species, the highest survival was recorded in milkfish (76.88 ± 1.74%) whereas mudcrabs recorded lowest survival 35.6%–39.69%. By reducing the stocking density (0.5 m^{-2}), it has been reported that mudcrabs could attain up to 90% survival rate (Trino et al., 1999) while at high density (1.5 nos./m^2) survival was reduced up to 34% (Trino & Rodriguez, 2002). The mortality of mudcrab during the grow-out phase has been largely attributed to cannibalism as it is reported that cannibalism affects survival, and directly related to stocking density (Kathirvel et al., 2004). To minimize the impact of cannibalism on survival, a useful management strategy is to routinely undertake partial harvests of crabs, leaving small size crabs to grow to harvest size, which can reduce the incidence of predation and reduce competition for feed (Christensen, Macintosh & Phuong, 2004; De Silva, 1980). Provision of shelters also would help to increase survival by minimizing antagonistic encounters (Kathirvel et al., 2004). Similarly, partial harvesting started after 4.5 months in the study, helped to maintain the stock in better condition. Also, optimization of feeding regime and ration can minimize the predatory and cannibalistic behaviour of mudcrab. However, further research is needed to standardize the factors for better survival rates of crab in polyculture system.

In the present pond trial, total productivity per crop was 4,533 and 3,694 kg/ha with mudcrabs contributing 53.69% and 60.56% to the total productivity in milkfish-mudcrab (T1) and mullet-mudcrab polyculture ponds respectively. Scientific grow-out farms of *S. serrata* yield 1.5–2 t/ha per each crop of 6 months with an individual weight of 300–350 g per crop (Linder, 2005; Trino et al., 1999). Polyculture of milkfish or mullets with shrimps recorded an average productivity of 500–1,800 kg/ha (Biswas, Ananda Raja, et al., 2012; James, 1996; Nammalwar & Kathirvel, 1988; Shofiquzzoha et al., 2001). The productivity level noticed in the present polyculture pond trials was much higher than those reported earlier. Insignificant production performance parameters of mudcrabs noticed in both the polyfarming system indicate the compatibility of crab with both the fish. Better growth rate of mullets compared with other finfish suggests that mullet could be a better species to coculture with mudcrab in polyfarming system. Being a benthophagus, mullets use the unutilized food matter and detritus generated in polyculture system.

Length–weight relation yields information on the general wellbeing of the cultured finfish and crustaceans, and shows marked variations during growth phase, gonad development and reproductive maturity of the sexes (Froese, 2006). The length–weight relationship is curvilinear with the exponent or regression coefficient value 3.0 indicating that the fish or crabs grow symmetrically while values other than 3.0 indicate allometric growth (Mohapatra, Mohanty, Mohanty & Dey, 2010; Sukumaran & Neelakantan, 1997; Tesch, 1971). In the present study, CW–length relationship between males and females of *S. serrata* indicated a different allometric pattern. The values for the regression coefficient or exponent (b) based on the regression equation remained below 3 in female crabs (b = 2.68), and was negatively allometric, while it was isometric or positively algometric (b = 3.3) for male crab. The present results corroborate the finding in *S. serrata* and *S. tranquebarica* captured from Chilka lake (Mohapatra et al., 2010) and *Portunus segnis* (Noori et al., 2015). However, other brachyuran crabs like *P. pelagicus* (Josileen, 2011; Sukumaran & Neelakantan, 1997) and *Callinectes danae* (Araújo & Lira, 2012), demonstrated positive allometry in both sexes. Also, in other portunids, such as *P. sanguinolentus* (Sukumaran & Neelakantan, 1997), an isometric growth was found in both males and females indicate interspecific variation. Though crustacean growth is a genetically related trait, biological changes during the reproductive cycle and abiotic factors can also influence growth. The earlier studies on width–weight relationship of *S. serrata* revealed that the value of exponent b to be 1.3, 2.9 and 3.2 in juvenile, adult female and adult male *S. serrata* respectively (Prasad, Reeoy, Kusuma & Neelakantan, 1989). Further, the b values indicated that the males are heavier due to heavy chelipede legs than females at a given width and weight. This tendency of *S. serrata* males being heavier than females in the present study is also in conformation with the earlier observation in other portunid crabs like *P. pelagicus and P. sanguinolentus* (Josileen, 2011; Noori et al., 2015; Prasad et al., 1989). The higher b value in male crabs can be attributed to allometric enlargement of male crabs chelae with sexual maturation (Miyasaka, Genkai, Goda & Omori, 2007; Mohapatra et al., 2010; Pinheiro & Fiscarelli, 2009). In contrast, Dhawan, Dwivedi and Rajamanickam (1976) reported that females of *P. pelagicus* are heavier than males at a given length in Goan waters indicating marked variation in the CW–weight relationship in portunids occurring at different places and growth stages.

The condition factors of cultured fish or shrimps are mainly influenced by exogenous or environmental factors, and endogenous parameters like rate of feeding and growth, reproductive stage, seasons etc (Froese, 2006; Pinheiro & Fiscarelli, 2009). In general, condition factor is based on the concept that heavier species of a given length are in a better condition. Low *K* value indicates fish/crabs are at low feeding intensity or spawning activity whereas higher *K* value indicates high feeding intensity and gradual increase in accumulated fat which suggests preparation for reproductive period (Sangun, Akamca & Akar, 2007). Relative condition factor gives an ideal picture when the selected populations are not following perfect cube law or isometric growth (Le Cren, 1951). Relative condition factor analysis indicated that 74.5% of male crabs had a relative condition factor above 1 (1–1.59) whereas only 30% of male crabs had condition factor between 0.5 and 0.99. Out of the harvested female mudcrabs, 52% crabs recorded relative condition factor above 1, and 48% recorded below 1 (0.6–0.99). Average condition factor among the male and female crabs in the present study did not show any significant difference ($P < 0.05$) though male crab had higher Kn value. On the contrary, Noori et al. (2015) reported a great difference in condition factor among different sexes of portunid crabs with female having the condition factor seven times higher than that of males even though males had 14% higher *b* value in CW–weight relation curve. This indicates that apart from sexual dimorphism, condition factor depends on stage of sexual maturity, gonad weight and reproductive phase of the animal. The higher condition factor observed in male or female crab in the present study indicates either they were in maturing or reproductive phase which demands further study to understand gonad development of the crabs.

In isometric growth, the fish follow cube law where shape of the fish is maintained as length or weight increases. However, allometric growth is common as the growth phase of bigger fish may appear different from the young ones. Length–weight analysis of harvested finfish in the regression equation for *M. cephalus* ($b = 2.4$), *C. chanos* ($b = 2.4$) and *L. parsia* ($b = 2.12$) was found to be negatively allometric with *b* value below 3 whereas *L. tade* show perfect cube law, $b = 2.99$ with isometric growth pattern. Though the value of b mainly depends on the growth pattern or shape and fatness of the species, other parameters like temperature, salinity, food (quantity, quality and size), sex, and time of year and stage of maturity also affect the isometric or algometric growth pattern of species (Froese, 2006; Le Cren, 1951). For example, milkfish reared in inland saline water with 25 ppt recorded b value of 2.49 correlated with better growth rate in comparison with conventional ponds ($b = 1.63$), and b value found to decrease as growth increases (Jana et al., 2006). Similarly, length–weight analysis of milkfish from grow-out pond, Raizada, Chadha, Ali, Kumar and Javed (2005) reported b value below 3. However, weekly length–weight analysis of milkfish reared in tide-fed ponds in West Bengal recorded a positive allometric growth (Biswas, Sundaray, Thirunavukkarasu & Kailasam, 2011) where fish were stocked at very low density (0.4 nos./m^2) in monoculture system compared with high density followed in the present study (1.5 nos./m^2). Similarly, length–weight analysis of wild-caught mullets from natural ecosystem was found to exhibit exponent *b* value 3 or near to 3 (Dankwa, 2011) in contrast to lower *b* value ($b < 3$) noticed for estuarine reared *M. cephalus* (Hora & Pillay, 1962). The lower *b* value ($b < 3$) noticed for milkfish and mullets in the present study compared with earlier reports can be attributed to the fact that length–weight in the present study was recorded from harvested fish at a later stage, and also different culture systems and environment compared with earlier reports. Critical biotic and abiotic factors behind the variation in length–weight analysis of same species need further investigation.

Relative condition factor analysis of fishes indicated that about 88%, 78% and 65% of *L. tade*, *M. cephalus* and *L. parsia* recorded relative condition factor 1 to 1.5, respectively, whereas only 24% of harvested *C. chanos* had a relative condition factor above 1. The lower *K* value (<1) for milkfish found to be in accordance with tide-fed monoculture ponds in India (Biswas et al., 2011) and Phillipines (Otubusin, 1990). Relative condition factor, Kn value for three mullets found to be above 1 indicates cultured mullets were robust, healthy and had good compatibility in the polyculture system compared with milkfish. Moreover, it is worthwhile to mention here that more than 88% of harvested *L. tade* had condition factor above 1 indicate its reproductive readiness and potential for captive broodstock rearing of *L. tade* in the ponds.

Polyculture systems are economically attractive and sustainable as most of the small and marginal farmers can utilize their on farm resources (Uddin, Azim, Wahab & Verdegem, 2009). From the economic analysis, it is obvious that polyculture ponds with different mullet species (T2) outperformed the milkfish treatment system (T1). The BCR analysis indicated 1.57 and 1.74 in the T1 and T2. The mullet-crab combination resulted in higher net income and BCR, mainly due to increased domestic value of mullet over milkfish. A significant rate of return over operational investment, 57%–74% indicates economic viability of both the polyculture system. Thus, the present study reveals that polyculture of mudcrabs with finfish can be economically more attractive and sustainable as this framing system can be adopted by small or marginal farmers in Sundarban in their tide-fed ponds without much investment.

5 | CONCLUSION

Various culture trials have been carried out and standardized in different geographic locations involving different aspects of mudcrab culture like nursery, grow-out or fattening. However, the evidence is still insufficient to assess its success as ideal polyculture species. Our study reveals that *S. serrata* with its good growth rate can be an alternative species for diversification of brackishwater farming in low saline coastal districts of Sunderbans, and adjacent areas where local orange crab maximum exploited. Further, the present findings indicate that polyculture of mudcrabs with economically important fish can be very lucrative and sustainable, as it results in maximum utilization of underutilized trophic resources and better productivity compared with monoculture. Also, polyculture of mudcrabs with different combination of mullets can be profitable due to availability of stockable seeds and consumer preference of mullets over milkfish in Sundarbans though both the system have location specific economic benefit. Economic indicators such as net profit, rate of return and BCR indicate that polyculture of mudcrab is a profitable and sustainable form of diversified coastal aquaculture. Commercialization of mudcrab hatchery to ensure adequate supply of mudcrab seeds in the country is a major bottleneck which demands joint effort from both private and public parties.

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