

Research Article

Shrimp polyculture: An economically viable and environmentally friendly farming system in low saline coastal region of Bangladesh

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Abstract

Shrimp polyculture with carp species has a great potential in economic development of Bangladesh. At present, shrimp polyculture technology is being most extensively used by shrimp farmers in the coastal regions of the country; however, the mechanism of scientific culture system is not well understood. Therefore, to evaluate the economic feasibility of shrimp (*Penaeus monodon*) polyculture with carp over mix culture of shrimp with prawn (*Macrobrachium rosenbergii*) and monoculture of shrimp, a study was conducted for a period of six months from July to December 2016 in selected ghers (modified low-lying rice fields with raised dykes, used for seasonal production of shrimp) at Kaliganj Upazila of Satkhira District, Bangladesh. Water quality was within the suitable range for shrimp culture. During the study period, environmental sustainability in terms of soil quality was achieved in polyculture of shrimp with carps and tilapia (*Oreochromis niloticus*). Growth performance and total yield of shrimp (2087.87 ± 34.47 kg/ha) and prawn (1789.47 ± 27.45 kg/ha) were also significantly ($P < 0.05$) improved in polyculture of shrimp with carps and tilapia compared to shrimp monoculture and mix culture of prawn and shrimp, respectively. The economic sustainability was also found to achieve in polyculture of shrimp with carps and tilapia (*Oreochromis niloticus*) in terms of the Benefit-cost ratio (BCR), which was significantly ($P < 0.05$) higher (2.49 ± 0.03) compared to other culture systems (1.96 ± 0.06 in shrimp monoculture and 1.26 ± 0.03 in shrimp and prawn mix culture).

Keywords: Shrimp polyculture, Ggrowth performance, Economic analysis, Low saline area

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Introduction

“Ghers”- are modified low-lying rice fields with raised dykes, used for seasonal production of shrimp, fish and other aquatic products (Kabir and Eva, 2014). Coastal aquaculture of Bangladesh is mainly composed of shrimp and prawn farming in gher (Shamsuzzaman *et al.*, 2017). In gher farming system, the water is inundated and logged for a long time and shrimp/prawn fries are put into it. It takes 3-6 months for the shrimp and prawns to be grown up and reach commercial size. At present the unit production of shrimp in gher is 0.71 MT/ha in Bangladesh and it produces 2.5% of the global production of shrimp (Shamsuzzaman *et al.*, 2017). However, unplanned shrimp cultivation sometimes diversely affects the soil and agriculture yields, ecology, biodiversity and sustainability of agriculture in the coastal regions of Bangladesh. Generally shrimp requires saline water for its normal growth and therefore, when monsoon rainfall comes early and rains heavily, the shrimp producers keep on adding extra salt into the water to ensure better growth of shrimp. The extra salt that is added to the field increases the level of soil salinity. Therefore, this saline water degrades the soil quality of fresh lands that adversely affect the local vegetation, plants and trees, crops, fishes, livestock, environment, ecology, and population health and disease patterns (Rahman *et al.*, 2013). More than 244,000 ha of land in southern Bangladesh are now reported by the Department of Fisheries as registered for shrimp or prawn

culture (Belton *et al.*, 2011) and an estimated 53% of this areas are known to be affected by salinity because of shrimp cultivation (Rahman *et al.*, 2013). Shrimp polyculture with other species (Martinez-Cordova and Martinez-Porchas, 2006), can be used in low saline coastal areas to minimize the prevailing problems in shrimp farming in Bangladesh as because diversification of species can diminish the impact of discharged effluent and assimilate most of the wastes generated from monoculture of shrimp (Zhen-Xiong *et al.*, 2001; Martínez-Porchas *et al.*, 2010). Shrimp polyculture also can increase the productivity of aquaculture species without hampering the existing environmental condition. Low saline shrimp polyculture is beneficial for controlling diseases caused by Ich (*Cryptocaryon irritans*), external trematodes, and most of ectoparasites and protozoa parasite that cannot live long in low salinity (Chakraborti and Bandyapadhyay, 2011), but can also increase many other diseases and parasites. The present study was designed to compare the growth and production performance of shrimp in monoculture, mix culture with prawn and in polyculture with carp fishes in low saline coastal area of Bangladesh.

Materials and methods

The experiment was conducted for a period of six months from July to December, 2016 in nine experimental gher under Kaliganj Upazila of Satkhira District (22°27'12.33"N and 89°02'05.03"E) (Fig. 1). The surface area of the studied gher was ranged

from 0.97 to 1.17 ha with an average depth of 1.5 m. All the ghers were

irregular in shape, rain fed and well exposed to sunlight.

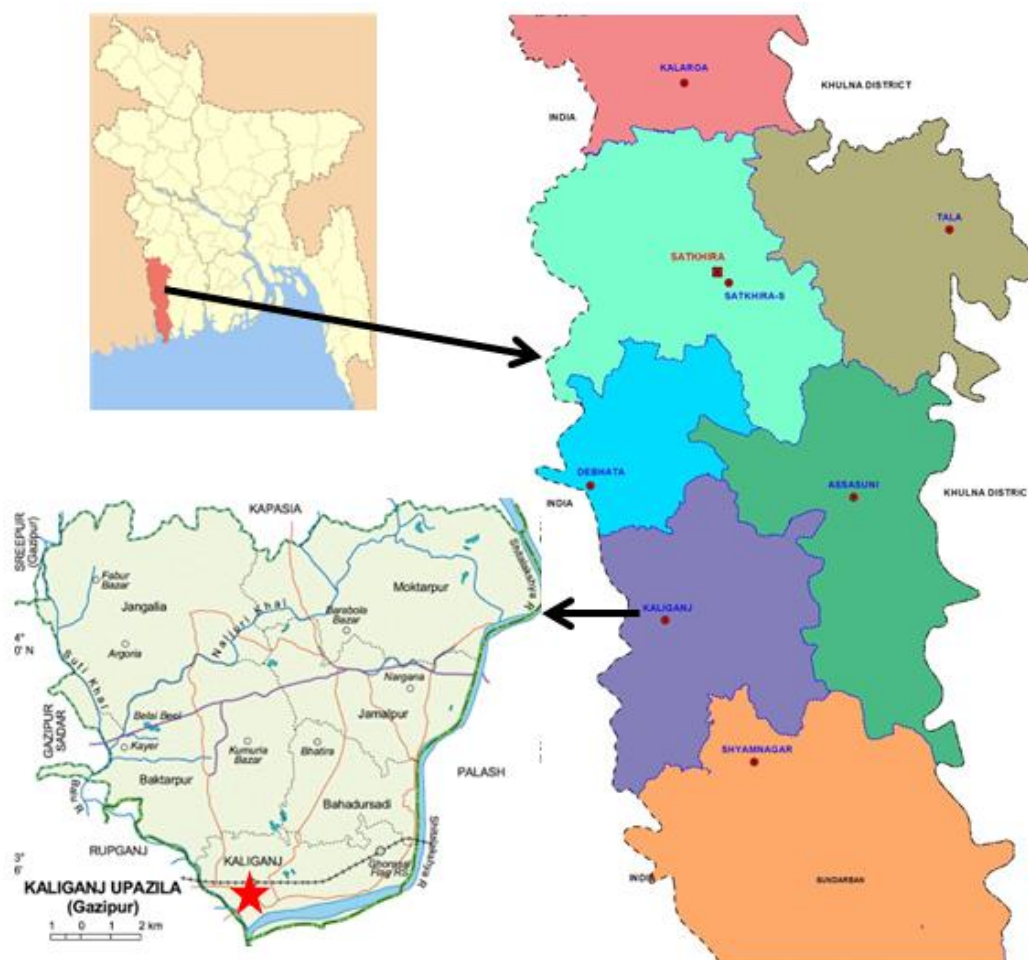


Figure 1: Location of the study area (indicated with red star).

Three different treatments (T_1 , T_2 , and T_3) were assigned each with three replications. The monoculture of shrimp (*Penaeus monodon*) with stocking density of 109915/ha (T_1), mix culture of shrimp and prawn (*Macrobrachium rosenbergii*) with stocking density of shrimp 74100/ha and prawn 28405/ha (T_2) and polyculture of shrimp, prawn and fish with stocking density of shrimp 61750/ha, prawn 24700/ha and fish 2470/ha were used. Average initial stocking weight of shrimp, prawn, silver carp (*Hypophthalmichthys*

molitrix), catla (*Catla catla*), rohu (*Labeo rohita*) and tilapia (*Oreochromis niloticus*) 0.25 ± 0.06 , 2.19 ± 0.03 , 104.33 ± 2.08 , 107.67 ± 2.52 , 106.00 ± 2.00 and 4.50 ± 0.25 g, respectively. Stocking density and stocking size of shrimp, prawn and fishes were selected according to the information gained from local fish farmers. Semi-intensive culture (where shrimp obtain nutrients primarily from artificial feeds and are stocked at higher densities, necessitating management practices, such as pond drainage to

maintain water quality) practice was followed in all the three treatments.

Aquatic weeds were removed from all the experimental ghers manually. Deep drains (about 2.5m) at the two border side of the ghers were made and soil was used to make the embankment. Embankments were made wider (1m) for preventing of escaping during the rainy season. Slope of embankment was 1:3 m. Inlet and outlet were placed to maintain the water level of the ghers. Unwanted fishes and other predatory species were removed through repeated netting from the ghers. After that, the ghers were ploughed and treated with lime (CaO, 240 kg/ha). Seven days after liming, all the ghers were fertilized with cow dung 1900 kg/ha, urea 24 kg/ha and Triple super phosphate (TSP) 18 kg/ha. One week after basal fertilization, all ghers were stocked with shrimp PL in treatment T₁, shrimp and Prawn PL in treatment T₂ and shrimp, prawn and fin fishes in treatment T₃. All the fishes were collected from hatchery and transported in oxygenated bags. Before stocking, PL was acclimatized to increase the survival rate. After stocking, weekly fertilization of urea 8 kg/ha and TSP 5 kg/ha was followed for all treatments. Dry cow dung, urea and TSP were applied fortnightly at the rate of 5 kg/decimal, 100 g/decimal and 50 g/decimal, respectively. Supplementary feeding was done twice daily at an average rate of 5% of biomass for the first 3 months and at 3% for the rest of rearing period. Water samples were collected monthly between 10:00 and 11:00 am for analysis of various physico-chemical

parameters using dark bottles. Water temperature and transparency were measured using a Celsius thermometer and a black and white standard colour coded Secchi disc of 30 cm diameter. Water pH was measured using an electronic pH meter (Jenway 3020) and dissolved oxygen (DO) was measured directly with a DO meter (Lutron DO-5509). Nitrate-nitrogen and phosphate-phosphorus concentrations were measured using the Hach Kit (DR/2010, a direct-reading spectrophotometer) with high range chemicals (Nitra Ver. 5 Nitrate Reagent Powder Pillows for 25 mL sample for Nitrate-nitrogen and Phos Ver. 3 Phosphate Reagent Powder Pillows for 25 mL sample for phosphate-phosphorus analysis). Ammonia-nitrogen and total alkalinity were measured using HACH kit (model FF-2, No. 2430-01; Loveland, CO, USA). Salinity was measured by using a hand Refractometer. Samples of bottom sediment were collected randomly before and after culture period from each treatment following the procedures described by Bangladesh Soil Research Institute (BSRI). Soil quality in terms of soil salinity (ppt), soil pH, organic matter (Walkley and Black, 1934) and total nitrogen (Hesse, 1971) of the selected ghers were monitored. Soil samples were tested in the laboratory of Soil Resource Development Institute (SRDI), Shyampur, Rajshahi.

Shrimp, prawn and fishes were sampled every 30 days by cast net for monitoring weight gain, survival rate (%) and specific growth rate (SGR % / day), and total yield (kg/ha) that were

calculated using the following equations:

Total yield (kg/ha) = Sum of individual weight of harvested fish

Weight gain (g) = Mean final weight (g) - Mean initial weight (g)

Survival rate (%) = (Fish harvested nos. / Fish stocked nos.) \times 100

SGR (%/day) = $[(\ln W_2 - \ln W_1) \times 100] / (t_2 - t_1)$,

Where, W_1 and W_2 are mean initial and final weight (g/fish) and t_1 and t_2 (days) are time of start and end of the culture period.

Net profit and benefit-cost ratio (BCR) were determined by the following formula:

Net profit = total returns from harvest – total cost of production

Benefit-cost ratio (BCR) = Net profit / total cost of production

Water quality, sediment quality, growth and production parameters (weight gain, survival rate, and SGR) and economic parameters (total cost, total profit and BCR) were analyzed by one-way ANOVA (Analysis of Variance). Sediment quality parameters were compared between before and after culture by paired *t*-test. When a mean effect was significant, the ANOVA was followed by Duncan's Multiple Range Test (DMRT) at 5% level of significance (Gomez and Gomez, 1984). The percentages and ratio data were analyzed using arcsine transformed data. All analysis was performed using SPSS (Statistical Package for Social Science) version 20.0 (IBM Corporation, Armonk, NY, USA).

Results

Mean values of water quality parameters recorded during the study period are shown in Table 1. Water temperature ranged from 20.00 to 30.50°C; water transparency varied

from 23.50 to 35 cm; pH ranged between 7.00 to 8.00; dissolved oxygen varied between 4.60 to 6.15 mgL⁻¹, salinity ranged between 2.70 to 3.10 ppt; nitrate-nitrogen was 0.05 to 0.17 mg/L; phosphate-phosphorus was 0.10 to 0.46 mg/L; ammonia-nitrogen was 0.01 to 0.15 mg/L and total alkalinity fluctuated between 112.00 to 140.00 mg/L. No significant change in the mean values of water temperature, transparency, pH, dissolved oxygen, salinity, and total alkalinity was observed ($p < 0.05$). But significant ($p < 0.05$) differences were observed in the mean values of nitrate-nitrogen, phosphate-phosphorus and ammonia-nitrogen among the treatments during the study period.

Mean values of soil quality parameters before and after the culture period are shown in Table 2. There was no significant difference ($p > 0.05$) in soil quality parameters among the treatments before fish culture. But after culture, significant differences ($p < 0.05$) were found for organic matter and total

nitrogen content among the treatments. comparing before and after culture
The outcomes of paired *t-test* condition are presented in Table 3.

Table 1: Mean (\pm SD) values of water quality parameters recorded from different treatments.

Parameters	Treatments			<i>p-value</i>
	T ₁	T ₂	T ₃	
Water temperature (°C)	26.96 \pm 0.19 ^a (20.12-30.50)	26.95 \pm 0.04 ^a (20.15-30.50)	26.89 \pm 0.22 ^a (20.00-30.50)	0.848
Water transparency (cm)	29.56 \pm 0.34 ^a (24.00-35.00)	29.53 \pm 0.27 ^a (23.50-35.00)	29.47 \pm 0.09 ^a (24.21-35.00)	0.922
pH	7.57 \pm 0.32 ^a (7.00-8.00)	7.58 \pm 0.23 ^a (7.00-7.85)	7.60 \pm 0.23 ^a (7.15-7.90)	0.748
Dissolved oxygen (mg/L)	5.27 \pm 0.06 ^a (4.60-6.15)	5.25 \pm 0.10 ^a (4.60-5.90)	5.28 \pm 0.37 ^a (4.80-5.80)	0.924
Salinity (ppt)	2.96 \pm 0.08 ^a (2.80-3.10)	2.93 \pm 0.05 ^a (2.70-3.10)	2.91 \pm 0.04 ^a (2.80-3.00)	0.721
Nitrate-nitrogen (mg/L)	0.10 \pm 0.01 ^b (0.05-0.14)	0.11 \pm 0.01 ^b (0.06-0.16)	0.13 \pm 0.01 ^a (0.07-0.17)	0.008
Phosphate-phosphorus (mg/L)	0.28 \pm 0.01 ^c (0.10-0.37)	0.31 \pm 0.01 ^b (0.11-0.42)	0.34 \pm 0.02 ^a (0.11-0.46)	0.004
Ammonia-nitrogen (mg/L)	26.96 \pm 0.19 ^a (20.12-30.50)	26.95 \pm 0.04 ^a (20.15-30.50)	26.89 \pm 0.22 ^a (20.00-30.50)	0.002
Total alkalinity (mg/L)	29.56 \pm 0.34 ^a (24.00-35.00)	29.53 \pm 0.27 ^a (23.50-35.00)	29.47 \pm 0.09 ^a (24.21-35.00)	0.416

T₁ = Monoculture of shrimp, T₂ = Mix culture of shrimp and prawn, and T₃ = Polyculture of shrimp with carps and tilapia. Mean values with different superscript letters in the same row indicate significant differences ($p < 0.05$).

Table 2: Mean (\pm SD) values of soil quality parameters recorded from different treatments before and after culture period.

Criteria	Parameters	Treatments			<i>p-value</i>
		T ₁	T ₂	T ₃	
Before culture	Soil salinity (ppm)	2.97 \pm 0.05 ^a	2.87 \pm 0.06 ^a	2.90 \pm 0.10 ^a	0.317
	pH	7.53 \pm 0.06 ^a	7.60 \pm 0.10 ^a	7.57 \pm 0.11 ^a	0.702
	Organic matter (%)	1.22 \pm 0.03 ^a	1.21 \pm 0.02 ^a	1.23 \pm 0.01 ^a	0.553
	Total nitrogen (%)	0.27 \pm 0.01 ^a	0.27 \pm 0.01 ^a	0.26 \pm 0.01 ^a	0.296
After culture	Soil salinity (ppm)	2.93 \pm 0.06 ^a	2.81 \pm 0.06 ^a	2.82 \pm 0.06 ^a	0.105
	pH	7.49 \pm 0.02 ^a	7.55 \pm 0.10 ^a	7.48 \pm 0.18 ^a	0.703
	Organic matter (%)	2.60 \pm 0.01 ^a	2.54 \pm 0.02 ^b	2.39 \pm 0.06 ^c	0.002
	Total nitrogen (%)	0.53 \pm 0.02 ^a	0.48 \pm 0.02 ^b	0.45 \pm 0.01 ^b	0.001

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia. Mean values with different superscript letters in the same row indicate significant differences ($p < 0.05$).

Table 3: Comparison of soil quality parameters before and after the culture period.

Parameters	Treatments	Before	After	t-value	p-value*
Soil salinity (ppt)	T ₁	2.97±0.05	2.93±0.06	0.634	0.591
	T ₂	2.87±0.06	2.81±0.06	2.429	0.136
	T ₃	2.90±0.10	2.82±0.06	1.979	0.186
pH	T ₁	7.53±0.06	7.49±0.02	1.710	0.229
	T ₂	7.60±0.10	7.55±0.10	3.500	0.073
	T ₃	7.57±0.11	7.48±0.18	2.563	0.124
Organic matter (%)	T ₁	1.22±0.03	2.60±0.01	-74.177***	0.000
	T ₂	1.21±0.02	2.54±0.02	-79.400***	0.000
	T ₃	1.23±0.01	2.39±0.06	-35.436***	0.001
Total nitrogen (%)	T ₁	0.27±0.01	0.53±0.02	-30.237***	0.001
	T ₂	0.27±0.01	0.48±0.02	-32.500***	0.001
	T ₃	0.26±0.01	0.45±0.01	-113.000***	0.000

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia. *Result from paired t-test, *** $p \leq 0.001$, mean±SD.

Organic matter (%) and total nitrogen (%) were significantly ($p < 0.05$) increased after culture period. The growth performance of shrimp, prawn and fish were analyzed in terms of final weight (Table 4), weight gain (Table 5), survival rate (Table 6) and specific growth rate (Table 7). Final weight of shrimp ranged between 31.48±0.91g in treatment T₁ to 39.50±0.66g in treatment T₃. Final weight of prawn was between 75.25±0.66g in T₂ and 83.92±1.13g in T₃. Final weight of *H. molitrix*, *C. catla*, *L. rohita* and *O. niloticus* were 1017.42±2.50, 1019.17±1.89, 817.75±7.51 and 294.70±5.90g, respectively. Highest weight gain (g) of shrimp was observed in treatment T₃ followed by T₂ and T₁ treatments, respectively. The weight gain of prawn was also highest in T₃ (81.71±1.07g) followed by T₂ (73.08±0.67g). The survival rate of shrimp ranged between 74.76±1.9 (T₁) to 85.60±0.40% (T₃). The survival rate of prawn was also highest in treatment T₃ (86.33±0.58 %). The survival rate of

fin fishes ranged between 91.44±0.69 (*O. niloticus*) to 97.22±0.69% (*L. rohita*). Specific growth rate of shrimp was highest in treatment T₃ (1.21±0.05%/day) and lowest in T₁ and T₂ (1.18±0.06 and 1.19±0.02%/day), respectively. Prawn had specific growth rate of 0.86±0.01%/day in T₂ and 0.88±0.00%/day in T₃. Specific growth rate of *H. molitrix*, *C. catla*, *L. rohita* and *O. niloticus* were 0.55±0.00, 0.54±0.01, 0.50±0.01 and 1.01±0.02%/day, respectively.

Total yields (kg/ha) of shrimp, prawn and fishes are shown in Table 8. The highest total yield of shrimp was obtained in T₃ (2087.87±34.47 kg/ha). Total yield of prawn was also highest in T₃ (1789.47±27.45 kg/ha). Extra total yield of fin fishes (1748.76±166.50 kg/ha) was also obtained from T₃ together with shrimp and prawn production. There was significant difference ($p < 0.05$) in total yield among three culture systems with highest total yield (5626.11±47.82 kg/ha) obtained from T₃ (polyculture system) followed by treatment T₂ (mix culture of shrimp

and prawn) and T₁ (monoculture of shrimp).

Table 4: Final weight (g) of shrimp, prawn, silver carp, catla, rohu and tilapia in T₁, T₂ and T₃ treatments for 180 days of culture period.

Species	Treatments		
	T ₁	T ₂	T ₃
<i>P. monodon</i>	31.48±0.91	34.83±1.38	39.50±0.66
<i>M. rosenbergii</i>		75.25±0.66	83.92±1.13
<i>H. molitrix</i>			1017.42±2.50
<i>C. catla</i>			1019.17±1.89
<i>L. rohita</i>			817.75±7.51
<i>O. niloticus</i>			294.70±5.90

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia.

Table 5: Weight gain (g) of shrimp, prawn, silver carp, catla, rohu and tilapia in T₁, T₂ and T₃ treatments for 180 days of culture period.

Species	Treatments		
	T ₁	T ₂	T ₃
<i>P. monodon</i>	31.25±0.93	34.57±1.41	39.23±0.60
<i>M. rosenbergii</i>		73.08±0.67	81.71±1.07
<i>H. molitrix</i>			913.08±2.40
<i>C. catla</i>			911.50±1.32
<i>L. rohita</i>			711.75±8.60
<i>O. niloticus</i>			290.20±6.14

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia.

Table 6: Survival rate (%) of shrimp, prawn, silver carp, catla, rohu and tilapia in T₁, T₂ and T₃ treatments for 180 days of culture period.

Species	Treatments		
	T ₁	T ₂	T ₃
<i>P. monodon</i>	74.76±1.91	77.22±1.07	85.60±0.40
<i>M. rosenbergii</i>		77.97±1.33	86.33±0.58
<i>H. molitrix</i>			95.00±1.00
<i>C. catla</i>			95.83±0.76
<i>L. rohita</i>			97.22±0.69
<i>O. niloticus</i>			91.44±0.69

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia.

Table 7: Specific growth rate (% bwd-1) of shrimp, prawn, silver carp, catla, rohu and tilapia in T₁, T₂ and T₃ treatments for 180 days of culture period.

Species	Treatments		
	T ₁	T ₂	T ₃
<i>P. monodon</i>	1.18±0.06	1.19±0.02	1.21±0.05
<i>M. rosenbergii</i>		0.86±0.01	0.88±0.00
<i>H. molitrix</i>			0.55±0.00
<i>C. catla</i>			0.54±0.01
<i>L. rohita</i>			0.50±0.01
<i>O. niloticus</i>			1.01±0.02

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia.

Table 8: Total yield (kg ha⁻¹) of shrimp, prawn, silver carp, catla, rohu and tilapia in T₁, T₂ and T₃ treatments for 180 days of culture period and 1 ha of gher.

Species	Treatments		
	T ₁	T ₂	T ₃
<i>P. monodon</i>	2585.79±30.85	1992.90±71.35	2087.87±34.47
<i>M. rosenbergii</i>		1666.71±39.27	1789.47±27.45
Sub total		3659.61±75.68	3877.34±230.65
<i>H. molitrix</i>			477.48±6.15
<i>C. catla</i>			482.49±3.90
<i>L. rohita</i>			589.11±3.90
<i>O. niloticus</i>			199.68±3.30
Sub total			1748.76±166.50
Total	2585.79±30.85 ^c	3659.61±75.68 ^b	5626.11±47.82 ^a

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia. Values are expressed as mean ±SD and values in the same row having different superscripts are significantly different ($p<0.05$).

Comparison of economic return among three treatments is shown in Table 9. The total input cost was significantly higher (607934.00±95.00 BDT/ha) in T₃ and lower (514656±1278.63 BDT/ha) in T₁. On the other hand, the total income was significantly higher (2123761.83±17920.71 BDT/ha) in T₃ and the lowest total income was obtained from T₁ (1163603.41±13883.05 BDT/ha).

Similarly, highest net profit was obtained from T₃ (1515827.83±17920.72 BDT/ha) followed by T₂ (1145714.26±34761.97 BDT/ha) and T₁ (648315.75±13677.01 BDT/ha), respectively. However, the Benefit-cost ratio (BCR) was significantly ($p<0.05$) higher in T₃ with a value of 2.49±0.03 followed by 1.96±0.06 in T₂ and 1.26±0.03 in T₁ respectively.

Table 9: Comparison of economic parameters among the treatments. Calculation was for 1 ha of ghers and 180 days of culture period.

Items	Treatments (mean values in BDT*)		
	T ₁	T ₂	T ₃
Gher preparation	3600.00	3600.00	3600.00
Inlet-outlet PVC pipe	7000.00	7000.00	7000.00
Liming	3400.00	3400.00	3400.00
Fertilizer	Urea	4800.00	4800.00
	TSP	2400.00	2400.00
	Cow dung	1200.00	1200.00
Seed cost	109915.00	179075.00	203034.00
Molasses + rice bran	3200.00	3200.00	3000.00
Feed	265000.00	265000.00	265000.00
Eggs	9114.00	9114.00	8500.00

Table 9 (Continued):

Items	Treatments (mean values in BDT*)		
	T ₁	T ₂	T ₃
Chemicals	9658.67	9658.67	5000
Pump machine	6500.00	6500.00	6500.00
Labour	36000.00	36000.00	36000.00
Netting	3500.00	3500.00	3500.00
Transportation	10000.00	10000.00	10000.00
Land rent**	30000.00	30000.00	30000.00
Others	10000.00	10000.00	10000.00
Total cost (BDT/ha)	514656 ^c	584447.67 ^b	607934.00 ^a
Total income (BDT/ha)	1163603.41 ^c	1730161.93 ^b	2123761.83 ^a
Net profit (BDT/ha)	648315.75 ^c	1145714.26 ^b	1515827.83 ^a
Benefit-cost ratio (BCR)	1.26 ^c	1.96 ^b	2.49 ^a

T₁=Monoculture of shrimp, T₂=Mix culture of shrimp and prawn, and T₃=Polyculture of shrimp with carps and tilapia. Values in the same row having different superscripts differ significantly ($p<0.05$).

*Currencies are given in Bangladeshi Taka, BDT (1 US\$ = 80 BDT). ** Valuation of land at its rental price.

Discussion

During the culture period, there was no significant ($p<0.05$) change in the mean values of water temperature, transparency, pH, dissolved oxygen, salinity and total alkalinity. There were significant differences ($p<0.05$) in the mean values of nitrate-nitrogen among the treatments. The highest value of nitrate-nitrogen was found in T₃ (0.13 ± 0.01 mg/L) and the lowest was found in T₁ (0.10 ± 0.01 mg/L). The recommended level of nitrate for shrimp farming is 0.0 to 0.3 ppm and for prawn farming is <0.1ppm (McNevin, 2004; Mazid, 2009). Presence of higher value of nitrate-nitrogen in T₃ in the present study might be due to higher fecal output of fishes. There was also significant difference ($p<0.05$) in the mean values of phosphate-phosphorus among three treatments with the highest value recorded in T₃ (0.34 ± 0.02 mg/L) and lowest value in T₁ (0.28 ± 0.01 mg/L) while both were above the

recommended limit for shrimp culture. According to Boyd (1998) the suitable range of phosphate-phosphorus in pond water is 0.005-0.2 mg/L. Presence of the highest value of phosphate-phosphorus in T₃ might be due to input of feeds and fertilization in the culture system, along with proper recycling of this waste into nutrients by fish activities in water. There was significant difference ($p<0.05$) in the mean values of ammonia-nitrogen among three treatments. Highest and lowest values were observed in T₃ (0.09 ± 0.01 mg/L) and T₁ (0.06 ± 0.00 mg/L), respectively, which was within the recorded ammonia-nitrogen range (0.07-0.28 ppm) found by Ahsan *et al.* (2014) in polyculture of prawn and carp. Presence of the highest value of ammonia-nitrogen in T₃ might be due to diversification of specimens, which increases fecal output in water column. There was no significant difference ($p<0.05$) between the mean values of soil salinity and pH before and after

culture period. That means these culture systems in low saline water had no impact on soil salinity and pH. There was a significant change ($p<0.05$) in the soil organic matter and total nitrogen content after culture period, with highest organic matter and total nitrogen were accumulated in T_1 (2.60 ± 0.01 and $0.53\pm0.02\%$) and lowest were in T_3 (2.39 ± 0.06 and $0.45\pm0.01\%$). As some subordinate species can feed on and assimilate most of the wastes generated from shrimp culture (dead plankton and the uneaten feeds), a higher efficiency of nitrogen utilization and diminishing of impact of effluent discharge was observed in polyculture system compared to monoculture system, which supports the findings of Zhen-Xiong *et al.* (2001) and Martínez-Porchas *et al.* (2010). There was also evidence that the diversification of species influenced the productivity status in polyculture system, which might be due to better decomposition and nutrient cycling through higher efficiency of nitrogen utilization. A similar observation was also made by Zhen-xiong *et al.* (2001); Hooper *et al.* (2005) and Balvanera *et al.* (2006).

There were significant differences ($p<0.05$) in the mean values of final weight and weight gain in shrimp among three treatments. This might be due to different stocking density of shrimp and species diversification. Although the stocking density between 10-20 PLs/m² is ideal for successful shrimp farms, recommended by Ramanathan *et al.* (2005), which was similar to T_1 (445 shrimp PL/deci), but lower stocking density in T_2 (300

shrimp PL and 115 prawn/deci) and T_3 (250 shrimp PL and 100 prawn/deci) gave more space and food for growth of shrimp and prawn. The increase in final weight and weight gain in the present study was attributed to be the lower stocking density, which was agreed with the findings of Chowdhury *et al.* (1991) and Ahsan *et al.* (2014). Less intra-species competition for food and space might also be responsible for higher growth in T_3 . Similar findings also was reported by Wohlfarth *et al.* (1985), who stated that polyculture fits sustainable aquaculture as the polyculture species do not compete for the same feed resources. Another reason for better growth performance in T_3 might be improved water quality in polyculture of shrimp, which is in agreement with the findings of Midlen and Redding (1998) and Zhang *et al.* (1999). They stated that, polyculture can improve water quality, since in monoculture farming systems; the excess nutrients that result from uneaten feed increases the phytoplankton, which in turn, changes the dissolved oxygen dynamics and brings negative ecological impact to the aquaculture activity itself.

Survival rate (%) of shrimp and prawn was higher in polyculture system as compared to mono and mix culture in the present study. Specific growth rates of shrimp and prawn were also significantly ($p<0.05$) increased with decreasing stocking density and with differences of culture system, which indicate that the growth rate was higher in lower densities which is in agreement with findings of Das *et al.* (1992), who

reported that the growth rate is inversely related to stocking density.

There was significant ($p<0.05$) difference in total yield among the three treatments. In T₃ total obtained yield was a 5626.11 ± 47.82 kg/ha/180 day which was 34.95% higher than that of T₂ and 54.04% higher than that of treatment T₁, this can be because polyculture causes proper utilization of available resources in more efficient way. Similar observation was noted by Bolognesi Da Silva *et al.* (2006). Higher fish production in polyculture system is also reported by Hossain and Islam (2006); Alam *et al.* (2008) and Anil *et al.* (2010).

There was significant difference ($p<0.05$) in total cost, total income, net profit and benefit-cost ratio (BCR) among the three treatments. The economic analysis showed that, total cost in treatment T₃ was 3.86% and 15.34% higher than that in treatments T₂ and T₁, respectively. But the total income in treatment T₃ was 18.53% and 45.21% higher than that in treatments T₂ and T₁, respectively. Net profit was also found higher in treatment T₃ than that in treatments T₂ and T₁. This might be due to higher growth rate and survivability of shrimp and prawn in T₃ (polyculture system) with additional production of fishes in this treatment. Higher net profitability in shrimp polyculture system was also found by Ali *et al.* (2013). It was found that, BCR was highest in treatment T₃ (2.49 ± 0.03) followed by T₂ (1.96 ± 0.06) and T₁ (1.26 ± 0.03), respectively. Similarly higher BCR was reported when shrimp was cultured with tilapia

in shrimp tilapia-polyculture system (Shofiquzzoha *et al.*, 2009).

In the present study, it was observed that polyculture system of shrimp with prawn and fish was better in all aspect of growth performance and economic feasibility (weight gain, specific growth rate, survival rate, total yield, net profit and BCR). Although the production cost was higher in polyculture system, it was more than counterbalanced by high productivity of shrimp, prawn and additional production from fishes. Polyculture of shrimp was also beneficial in terms of environmental well-being of low saline coastal areas of Bangladesh. So, polyculture of shrimp with fishes would be more profitable to fish farmers than mix culture of shrimp with prawn and monoculture of shrimp, which will promote the national economy and reduce environmental impact caused by shrimp monoculture.

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