Journal of Applied Ichthyology

J. Appl. Ichthyol. 28 (2012), 116–122

ISSN 0175–8659

Received: January 9, 2011
Accepted: July 28, 2011
doi: 10.1111/j.1439-0426.2011.01909.x

Evaluation of productions and economic returns from two brackishwater polyculture systems in tide-fed ponds

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Summary

To compare the production and economic performance of two polyculture systems with different species combinations in brackishwater tide-fed ponds, a 180-day trial was carried out. In the first combination (T1), mullets (*Mugil cephalus*, *Liza tade* and *L. parsia* at 3 : 1 : 1.3 ratio) and tiger shrimp (*Penaeus monodon*) and in the second (T2), milkfish (*Chanos chanos*) and tiger shrimp were stocked keeping the fishes and shrimp at 8000 and 20 000 numbers ha^{-1}, respectively, in both treatments with duplicate ponds. Since shrimp was an important component of these two systems with open water exchange, the dynamics of heterotrophic bacteria (THB) including *Vibrio* spp. (TVC) and the occurrence of viral infection agents were studied to understand the disease risks. Among the fishes in T1, *M. cephalus* attained the highest final weight of 92.29 ± 4.36 g followed by *L. tade* and *L. parsia* with 80.40 ± 4.02 and 54.02 ± 2.11 g, respectively. *C. chanos* in T2 had the highest net weight gain (127.85 g) and daily weight gain (0.71 g day^{-1}), while *M. cephalus* in T1 attained the highest specific growth rate (1.60% day^{-1}). Growth parameters of tiger shrimp were almost similar in both treatments, with no significant differences ($P > 0.05$). Though total production of fishes and shrimp was lower in T1 (689 kg ha^{-1} 180 day^{-1}), it was not significantly different ($P > 0.05$) from T2 (721 kg ha^{-1} 180 day^{-1}). Monthly THB and TVC were not alarming and the absence of viral infections in shrimp indicated no disease risk. Total income from T1 was significantly higher ($P < 0.05$) than that of T2, but net income and benefit-cost ratio were insignificantly different between the treatments ($P > 0.05$). The present findings indicate that upon availability of stocking materials, both polyculture systems would be suitable farming options.

Introduction

The concept of polyculture is based on the fact that rearing of two or more compatible aquatic species together will result in higher production compared to monoculture (Eldani and Primavera, 1981). Traditional brackishwater polyculture practices are age-old and carried out in large impoundments known as '*bheries*' since 1829 in India (Lovatelli, 1990). In *bheries*, large numbers of fish and shrimp seeds brought in through tidal water and partial stocking are reared for a period of 6–7 months (Biswas et al., 2009). In the process of tidal water exchange, some predatory and carnivorous fishes such as *Lates calcarifer*, *Megalops cyprinoides*, *Eleutheronema tetradactylum*, *Therapon jarbua*, *Glossogobius giuris* etc. gain accidental entry and lower the production. Among the finfish species, mullets, *Mugil cephalus*, *Liza tade*, *L. parsia* and milkfish, *Chanos chanos* are non-carnivorous and have good consumer preference and market price. Seeds of these fishes are abundantly available and can be cultivated along with shrimp in pond systems. Polyculture of shrimp has been conducted with a wide variety of finfishes such as milkfish (Eldani and Primavera, 1981; Pudadera and Lim, 1982; Apud, 1985; Kuntiyo and Baliao, 1987; James, 1996), mullets (James, 1996; Shofiquzzoha et al., 2001), tilapias (Samonte et al., 1991; Wang et al., 1998; Tian et al., 2001; Yuan et al., 2010) and bivalves (Hunt, 1991; Hopkins et al., 1993; Tian et al., 2001). However, due to incidence of white spot viral disease, semi-intensive shrimp farming is now practiced as a closed pond farming system adopting bio-security measures with no water exchange (Panigrahi et al., 2009). This closed system cannot be followed in a tide-fed polyculture system with shrimp as an important component, and therefore risks of bacterial and viral diseases need to be evaluated in such systems. Bacteria of the genus *Vibrio* are often present in the coastal aquatic ecosystems in which shrimp grow naturally or are farmed (Ruangpan and Kitao, 1991) and are reported causing diseases in shrimp farming worldwide (Ruangpan and Kitao, 1991; Jiravanichpaisal et al., 1993; Lightner, 1993; Karunasagar et al., 1994; Abraham et al., 1998; Anand Ganesh et al., 2010).

In this context, the present experiment was conducted in brackishwater tide-fed ponds to compare the performance of two polyculture systems with different species combinations for economic viability and to assess the disease risks through a study of the dynamics of heterotrophic bacteria, including *Vibrio* spp. and the occurrence of viral disease agents in these two farming systems.

Materials and methods

This experiment was carried out for a period of 180 days (6 months) during August 2008 to January 2009 in the brackishwater tide-fed farm of the Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA), Kakdwip (Lat. 21°51′15.01″–21°51′30.77″N, Long. 88°10′58.44″–88°11′12.09″E), South 24 Parganas, West Bengal, India, located in the Sunderbans. Four earthen ponds each 0.1 ha (1 ha = 10 000 m^2) were selected. The ponds were first dried and exposed to sunlight before beginning the experiment. Lime (CaO) was applied to the pond bottom at 500 kg ha^{-1}. After 7 days of lime application, ponds were filled with

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strained brackishwater from a nearby creek of the Muriganga River to a depth of 50 cm. On day 9, ponds were fertilized with organic manure, cattle dung and inorganic fertilizers, urea and single super phosphate (SSP) at 2000, 50 and 50 kg ha^{-1}, respectively. Ponds were left for 7 days to ensure growth of natural fish food organisms and water level was finally increased to 120 cm.

Ponds were stocked with two different species combinations. In the first treatment (T1), mullets (*M. cephalus*, *L. tade*, *L. parsia*) and tiger shrimp (*Penaeus monodon*); in the second treatment (T2), milkfish (*C. chanos*) and tiger shrimp were stocked keeping fishes and shrimp at 8000 and 20 000 numbers ha^{-1}, respectively (Table 1). Each treatment had two replicate ponds. Brackishwater farm ponds of uniform size for this kind of field study were not available, thus the experiment was restricted to two replicates. Low cost pellet feed prepared from locally available ingredients (mustard cake, rice bran, wheat flour, fishmeal etc.) was given as supplementary feed at 2–5% body weight per day. Daily ration was distributed in two equal quantities in the morning (09:00 hours) and afternoon (14:00 hours). Proximate composition of feed (Table 2) was analysed as per Association of Official Analytical Chemists (1989). The feed was provided in feed trays for fish and broadcast for shrimp. In the feed trays, both the morning and afternoon quantities were given in two split doses at 1-h intervals (09:00, 10:00 hours and 14:00, 15:00 hours) to meet the requirements of fish of various sizes. Initially, crumbled feed was given; as the culture progressed, the pellet size was increased (2 mm × 3–4 mm) to fit changes in fish and shrimp sizes. 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, 80, 70 and 60% in the first, second, third-fourth and fifth-sixth month of culture, respectively.

Water exchange at 40–50% of total pond water was carried out monthly maintaining a 120 cm water level throughout the culture period. Tidal water entering a reservoir pond located in the same farm was allowed to settle for 2–3 h and then drawn into culture ponds to avoid difference in water temperature. Water exchange was completed in 2–3 h. As the culture operation was conducted in the monsoon season, reduction in water pH due to precipitation was corrected by fortnightly application of lime stone powder at 250 kg ha^{-1}. Cattle dung, urea and SSP were applied at 300, 25 and 25 kg ha^{-1}, respectively, at 15-day intervals to maintain sustained desirable water quality in conjunction with optimum natural productivity. The mean length and weight increments were computed from random samples of fish (n = 70 for *M. cephalus*, 25 for *L. tade*, 30 for *L. parsia* from each replicate pond of T1, and n = 125 for *C. chanos* from each replicate pond of T2) and tiger shrimp, *P. monodon* (n = 205 from each replicate pond of both treatments) at 15-day intervals for feed quantity calculation. Fish and shrimp were weighed using a digital electronic balance (Afcoset, model ER200A) having 0.0001 g precision and length was measured with a slide caliper. Pond water samples were collected between 09:00 and 10:00 hours at 15-day intervals to measure important parameters. Temperature (Celsius), pH, dissolved oxygen, transparency, total alkalinity, ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P) and gross primary productivity were recorded following standard methods (American Public Health Association, 1998), and salinity was assessed using a refractometer (ATAGO, Japan). NH_3-N, NO_2-N, NO_3-N and PO_4-P concentrations were determined using a digital double-beam spectrophotometer (model UV2310; Techcomp).

Table 2
Proximate composition of feed used in mullets-tiger shrimp and milkfish-tiger shrimp polyculture systems

Organic matter^{a} (% DM)	81.31
Crude protein (% DM)	30.17
Lipid (% DM)	4.15
Crude fibre (% DM)	25.11
Ash (% DM)	18.69
Acid insoluble ash (% DM)	13.75
Nitrogen free extract^{b} (% DM)	21.88
Gross energy content (kcal kg^{-1})	4003

DM, Dry matter.
^{a}Organic matter = 100−Ash %.
^{b}Nitrogen free extract = 100−(Crude protein % + Lipid % + Crude fibre % + Ash %).

The total viable heterotrophic bacterial (THB) and *Vibrio* count (TVC) were estimated monthly from pond water samples to monitor the microbial dynamics throughout the culture. For this purpose, 1 ml of water from the respective

Table 1
Species combinations, stocking density (SD), average body weight (ABW), net weight gain (NWG), daily weight gain (DWG), specific growth rate (SGR), survival, apparent feed conversion ratio (AFCR), production of experimental species in mullets-tiger shrimp (T1) and milkfish-tiger shrimp (T2) polyculture treatments. Mean ± SEM for initial and final weight calculated based on pooled data of individual fish ⁄ shrimp of two replicate ponds (n = 140, *Mugil cephalus*; 50, *Liza tade*; 60 *Liza parsia*; 250, *Chanos chanos*; 410 *Penaeus monodon*). NWG, DWG, SGR, survival, AFCR and production = mean values of two replicates

Treatment	Species combination	SD (Nos. ha^{-1})	ABW (g)		NWG (g)	DWG (g day^{-1})	SGR (% day^{-1})	Survival (%)	AFCR	Production (kg ha^{-1} 180 day^{-1})
			Initial	Final						
T1	*Mugil cephalus*	4500	5.20 ± 0.22	92.29 ± 4.36	87.09	0.48	1.60	85.7	1.74	356
	Liza tade	1500	7.60 ± 0.24	80.40 ± 4.02	72.80	0.41	1.31	77.9		93
	L. parsia	2000	10.68 ± 0.56	54.02 ± 2.11	43.34	0.24	0.90	43.8		47
	Penaeus monodon	20 000	0.11 ± 0.02	18.00 ± 0.64	17.89	0.10	0.38	53.7^{a}		193^{a}
										689
T2	*Chanos chanos*	8000	15.43 ± 1.02	143.28 ± 7.73	127.85	0.71	1.24	48.6	1.99	557
	P. monodon	20 000	0.11 ± 0.02	17.01 ± 0.72	16.90	0.09	0.35	48.0^{b}		164^{b}
										721

Means with different superscripts for each species in a column differ significantly ($P < 0.05$).

pond was serially diluted in autoclaved normal saline, plated aseptically under laminar airflow on sterilized Tryptone Soya Agar (TSA) and Thiosulfate Citrate Bile Sucrose Agar (TCBS) (HiMedia Laboratories, Mumbai) plates in duplicate. These culture plates were incubated at 30°C for 24 h, then examined for THB and TVC. The number of colonies formed on each plate was multiplied by the reciprocal value of dilution to determine the colony numbers per unit sample volume of water. The shrimp samples were collected at fortnightly intervals and screened through Polymerase Chain Reaction (PCR) for viral infections such as white spot disease (WSD) by two-step PCR amplification as reported by Kimura et al. (1996), infectious hypodermal and haematopoietic necrosis virus (IHHNV) (OIE, 2003), yellow head virus (YHV) and gill associated virus (GAV) using the IQ 2000™ YHV / GAV detection kit (Farming IntelliGene Tech. Corp., Taiwan).

After 180 days of culture, fish and shrimp were partially harvested using a drag net. The pond water was then completely drained off to capture the remaining stock. Fish and shrimp performances in the two treatments were evaluated in terms of final average body weight (ABW, g), net weight gain (NWG, g), daily weight gain (DWG, g day^{-1}), specific growth rate (SGR, % day^{-1}), apparent feed conversion ratio (AFCR), survival (%), species-wise production and total production (kg ha^{-1} 180 day^{-1}). Mean ± SEM for initial and final weights were calculated based on pooled data of individual fish / shrimp of two replicate ponds (n = 140 for *Mugil cephalus*, 50 for *Liza tade*, 60 for *Liza parsia* in T1, 250 for *Chanos chanos* in T2, and 410 for *Penaeus monodon* in both the treatments), whereas NWG, DWG, SGR, AFCR, survival and production were determined for each replicate.

- NWG = mean final weight−mean initial weight
- DWG = (mean final weight−mean initial weight) / rearing duration in days
- SGR = [(ln final weight−ln initial weight) / rearing duration in days] × 100
- AFCR = total feed intake / total biomass gain
- Survival = (number of fish harvested / number of fish stocked) × 100

An economic analysis was performed to estimate the net income and benefit-cost ratio (BCR). Net income was calculated as:

Net income = Total income−total expenditure

BCR was determined as:

BCR = Total income / total expenditure

Comparison of fish and shrimp performance parameters, economic analysis and microbial populations between the two treatments was made with an independent sample *T*-test for equality of means and ANOVA using SPSS for Windows v.17.0 programme (SPSS Inc., Chicago, IL). All data are expressed as mean ± SEM.

Results

Water quality parameters did not show any marked variations among treatments (Table 3). However, salinity of the experimental ponds ranged from 3.4–8.2 g L^{-1} in T1 and 3.7–9.0 g L^{-1} in T2 throughout the culture duration. Fish and shrimp were healthy and no infection or disease occurred. All fish and shrimp performance data recorded during culture and parameters calculated at the end of experiment are presented in Table 1.

Among the fishes in T1, *M. cephalus* attained the highest final ABW of 92.29 ± 4.36 g followed by *L. tade* and *L. parsia* with 80.40 ± 4.02 and 54.02 ± 2.11 g, respectively. However, *C. chanos* in T2 grew to be larger than the fishes of T1. Milkfish in T2 had the highest NWG (127.85 g) and DWG (0.71 g day^{-1}), while *M. cephalus* in T1 attained the highest SGR (1.60% day^{-1}). Growth of *P. monodon* was almost similar in both the treatments, with no significant differences ($P > 0.05$). Similarly, NWG, DWG and SGR were not different for tiger shrimp in the two treatments ($P > 0.05$). Growth increment for weight of fishes and shrimp showed an increasing trend in both treatments (Figs 1 and 2). In this study, although AFCR in both the treatments was insignifi-

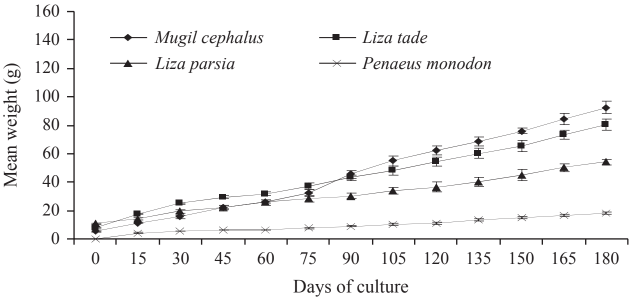

Fig. 1. Weight increment (mean ± SEM) of *Mugil cephalus* (n = 140), *Liza tade* (n = 50), *Liza parsia* (n = 60) and *Penaeus monodon* (n = 410) in mullets-tiger shrimp polyculture system. Mean ± SEM was calculated during each sampling at 15-day intervals by pooling data of individual fish / shrimp of two replicate ponds

Table 3
Physico-chemical characteristics of experimental pond water collected 09:00–10:00 hours at 15-day intervals from mullets-tiger shrimp (T1) and milkfish-tiger shrimp (T2) polyculture ponds

Parameters	T1 (n = 26)	T2 (n = 26)
Temperature (°C)	27.5 ± 0.7 (21.0–33.5)	27.4 ± 0.7 (21.0–33.0)
pH	8.16 ± 0.06 (7.75–8.78)	8.11 ± 0.04 (7.75–8.51)
Dissolved oxygen (mg L^{-1})	7.6 ± 0.2 (5.2–8.8)	7.7 ± 0.1 (6.4–8.8)
Transparency (cm)	33.1 ± 0.7 (28.0–40.0)	33.0 ± 0.6 (28.0–40.0)
Total alkalinity (mg $CaCO_3$ L^{-1})	154.6 ± 4.5 (92.0–200.0)	160.8 ± 2.9 (136.0–184.0)
Salinity (g L^{-1})	5.3 ± 0.3 (3.4–8.2)	5.6 ± 0.3 (3.7–9.0)
Ammonia-nitrogen (mg L^{-1})	0.019 ± 0.004 (0.002–0.085)	0.020 ± 0.003 (0.003–0.046)
Nitrite-nitrogen (mg L^{-1})	0.024 ± 0.004 (0.001–0.071)	0.020 ± 0.004 (0.002–0.069)
Nitrate-nitrogen (mg L^{-1})	0.062 ± 0.007 (0.003–0.129)	0.054 ± 0.008 (0.006–0.134)
Phosphate-phosphorus (mg L^{-1})	0.057 ± 0.003 (0.034–0.089)	0.052 ± 0.003 (0.033–0.091)
Gross primary productivity (mg C m^{-3} h^{-1})	315.38 ± 17.47 (140.01–499.96)	301.96 ± 17.05 (120.07–456.20)

Values indicate mean ± SEM; Figures in parentheses are given in ranges.

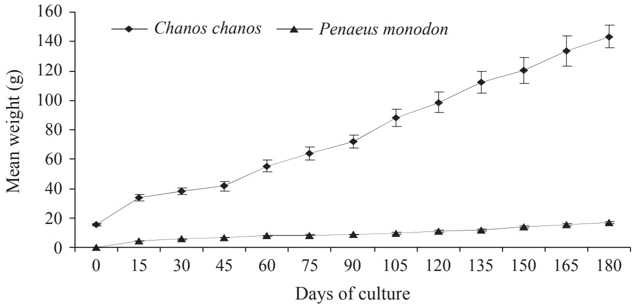

Fig. 2. Weight increment (mean ± SEM) of *Chanos chanos* (n = 250) and *Penaeus monodon* (n = 410) in milkfish-tiger shrimp polyculture system. Mean ± SEM was calculated during each sampling at 15-day intervals by pooling data of individual fish/shrimp of two replicate ponds

cantly different ($P > 0.05$), T1 recorded a lower value of 1.74 than T2 (1.99).

The highest survival of 85.7% was recorded for *M. cephalus* followed by *L. tade* (77.9%) in T1. Survival of *P. monodon* was significantly higher in T1 than T2 ($P < 0.05$). Among the fishes, production of *C. chanos* was the highest (557 kg ha^{-1} 180 day^{-1}) in T2 followed by *M. cephalus* (356 kg ha^{-1} 180 day^{-1}), *L. tade* (93 kg ha^{-1} 180 day^{-1}) and *L. parsia* (47 kg ha^{-1} 180 day^{-1}) in T1. However, tiger shrimp production in T1 (193 kg ha^{-1} 180 day^{-1}) was significantly higher than in T2 ($P < 0.05$). Although total production of fishes and shrimp was lower in T1 (689 kg ha^{-1} 180 day^{-1}), it was not significantly different ($P > 0.05$) from that of T2 (721 kg ha^{-1} 180 day^{-1}).

THB and TVC in polyculture ponds were lowest with 0.06×10^5 and 0.35×10^3 cfu ml^{-1} in the initial phase of culture and peaking with 8.38×10^5 and 1.28×10^3 cfu ml^{-1} at 131 and 101 days, respectively. Monthly THB and TVC exhibited increasing trends with the progress of the culture period (Figs 3 and 4). Influence of the age of the culture over the THB was significant ($P < 0.05$), whilst treatment and age of culture interaction had significant roles in the THB ($P < 0.05$) and TVC ($P < 0.01$). The shrimp produced were healthy and free of WSD, IHHNV, YHV and GAV diseases throughout the culture as assessed by PCR screening.

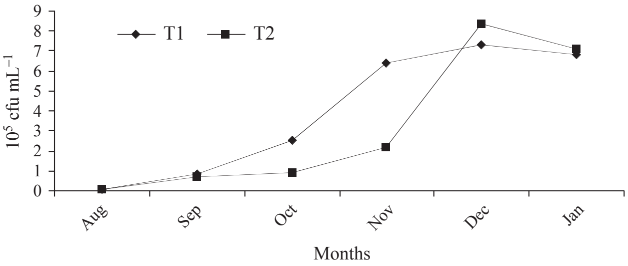

Fig. 3. Monthly variation of total viable heterotrophic bacterial count (mean of two replicates) in mullets-tiger shrimp (T1) and milkfish-tiger shrimp (T2) polyculture systems

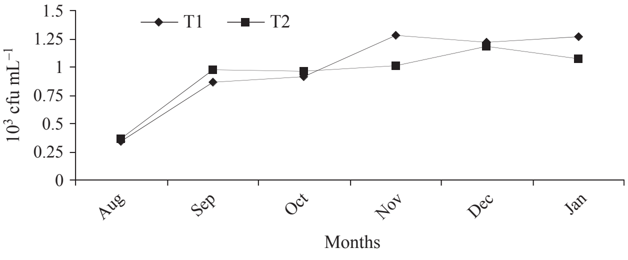

Fig. 4. Monthly variation of total *Vibrio* count (mean of two replicates) in mullets-tiger shrimp (T1) and milkfish-tiger shrimp (T2) polyculture systems

A simple economic analysis was performed to estimate the net income and BCR derived from the two polyculture systems (Table 4). Although the total income from T1 (INR 10 368) was significantly higher ($P < 0.05$) than that of T2 (INR 8521), the net income and BCR from the two treatments were not different ($P > 0.05$).

Discussion

The recorded water quality parameters were within the optimum ranges for brackishwater shrimp and finfish culture (Bhowmik et al., 1992; Ali et al., 1999; Chakraborti et al., 2002). Monthly water exchange and fortnightly application of lime and fertilization contributed to optimum water quality. Low temperature observed during the winter season might be responsible for low survival and growth of shrimp (Wyban et al., 1995; Yuan et al., 2010).

The growth and production performances of finfish and tiger shrimp were similar in T1 and T2 ponds, indicating both the species combinations are optimum. *M. cephalus* grew to be bigger among mullet species in T1 due to its inherently higher growth potential. The growth of *M. cephalus* observed in this study was more than in earlier reports (James et al., 1985; Shofiquzzoha et al., 2001). Similarly, *L. parsia* showed better growth compared to the observations of James et al. (1985) and Shofiquzzoha et al. (2001). The growth of *C. chanos* was the highest among finfishes in the two systems. This may be attributed to the fact that milkfish has a faster growth rate. In a 120-day milkfish-tiger shrimp polyculture, milkfish exhibited higher daily weight gains of 1.28–1.65 g day^{-1} (Eldani and Primavera, 1981), while milkfish in polyculture with red seaweed obtained higher mean growth rates of 2.47–2.57 g day^{-1} (Guanzon et al., 2004) compared to the present observation of 0.71 g day^{-1}. Tiger shrimp exhibited slow growth rates that were 33–37% lower than the growth in standard monoculture practice from tide-fed ponds of the Sunderbans, India (Chakraborti et al., 2002), where it attained average body weight of 26.95–28.57 g in 101 days. In a polyculture of mullets and shrimp, Shofiquzzoha et al. (2001) found that shrimp grew 32.79–38.82 g in 195 days, while in a milkfish-shrimp polyculture trial, Eldani and Primavera (1981) reported average shrimp weight of 36.2–46.5 g in 120 days of culture. Polyculture of tiger shrimp and tilapia, *Oreochromis niloticus* in two densities of 6000, 6000 and 6000, 4000 ha^{-1} resulted in average shrimp growth of 25.81 and 29.96 g, respectively, in the Philippines (Gonzales-Corre, 1988). However, Nammalwar and Kathirvel (1988) obtained 12.8–17.8 g *P. monodon* after 6 months of culture with milkfish in a polyculture system. The retarded growth of tiger shrimp in the present study might have been the result of food competition with finfishes (Yuan et al., 2010) in both polyculture systems.

Survival rates of finfishes and shrimp were significantly better in the mullets-shrimp species combination than milkfish-shrimp polyculture. Survival of *M. cephalus* was higher compared to 43–63% for a monoculture of 200 days duration (James et al., 1985) and 56.67–64.67% in polyculture with tiger shrimp for 195 days rearing (Shofiquzzoha et al., 2001). Survival of *L. parsia* was lower than the observation of Shofiquzzoha et al. (2001), where it was 62.89–68.17%. Milkfish survival was the lowest among finfishes and it was lower

Table 4
Comparison of economic returns, mullets-tiger shrimp (T1) vs milkfish-tiger shrimp (T2) polyculture systems. Values for total income, net income and benefit-cost ratio = means of two replicates

		T1			T2			
		Expenditure	Income		Expenditure		Income	
Items		INR[b]	Items	INR	Items	INR	Items	INR
Fish seed[a]	*M. cephalus*	450 × 5 = 2250	35.57 × 140 =	4980	–	–	–	–
	L. tade	150 × 3 = 450	9.29 × 140 =	1301	–	–	–	–
	L. parsia	200 × 1.5 = 300	4.72 × 130 =	614	–	–	–	–
	C. chanos	–	–	–	800 × 2 =	1600	55.67 × 100 =	5567
	P. monodon	2000 × 0.7 = 1400	19.30 × 180 =	3474	2000 × 0.7 =	1400	16.41 × 180 =	2954
Fish feed[c]		109.69 × 12 = 1316	–	–	118.44 × 12 =	1421	–	–
Fertilization		830	–	–		830	–	–
Lime		1100	–	–		1100	–	–
Others		400	–	–		400	–	–
Total expenditure		8016	Total income	10 368[x]	Total expenditure	6721	Total income	8521[y]
Net income: INR 2316 and 23 160 ha^{-1}					Net income : INR 1768 and 17 680 ha^{-1}			
Benefit-cost ratio (BCR): 1.29					Benefit-cost ratio (BCR): 1.26			

Calculation for 0.1 ha pond and 180 days experimental duration; Means with different superscripts in a row differ significantly ($P < 0.05$).
[a] Expressed as number of seed × price of each seed.
[b] INR, Indian currency, rupee (100 INR = 2.14 US$).
[c] Expressed as total kg of feed × price per kg.
[x,y] indicate significant difference in total incomes.

compared to 90–95% and 93–96% in polyculture with tiger shrimp (Eldani and Primavera, 1981) and red seaweed (Guanzon et al., 2004), respectively. Tiger shrimp had a significantly inferior survival in culture with milkfish compared to mullets. In this culture system, it might have encountered food competition to a greater extent with milkfish, which is a very active, robust and continuous feeder (Chiu et al., 1987; Lückstädt and Reiti, 2002), and shrimp probably subsisted mainly on natural food. Shrimp survival rates of 48.0–53.7% are consistence with the observation in shrimp-milkfish polyculture (Eldani and Primavera, 1981). However, it was higher in comparison to shrimp survival of 24.92–39.09% in cultures with mullets (Shofiquzzoha et al., 2001) and of 20.6–35.3% in polyculture with milkfish (Nammalwar and Kathrivel, 1988).

The production performance of finfishes and total production in both systems were similar. However, tiger shrimp production was significantly higher in culture with mullets, which may be attributed to better survival of shrimp and likely indicating better compatibility with mullets than milkfish in a polyculture system. The production level in mullets-shrimp polyculture was higher than the previous report of 242.67–294.98 kg ha^{-1} in polyculture of *M. cephalus*, *L. parsia*, *Rhinomugil corsula* and *P. monodon* stocked at 1000, 8000, 2000–4000 and 12 500–15 000 ha^{-1}, respectively (Shofiquzzoha et al., 2001). On the other hand, Eldani and Primavera (1981) obtained a total production of 316–376 kg milkfish ha^{-1} and 88–116 kg shrimp ha^{-1} in polyculture systems, when they were stocked at 2000 and 4000–8000 numbers ha^{-1}, respectively.

In any aquatic system, environmental parameters such as temperature, salinity, pH and dissolved oxygen play a pivotal role in the distribution of the bacteria (Palaniappan, 1982). The increased microbial load towards the end of the culture could be due as the culture advances to the accumulated uneaten feed, faeces and plankton die-offs (Avnimelech et al., 1995; Sharmila et al., 1996; Anand Ganesh et al., 2010). With proper pond management of water exchange and lime application, optimum environmental parameters were maintained throughout the culture, which helped control the microbial load in the aquaculture systems. Although the treatment and age of culture interaction had significant differences in THB and TVC, no disease outbreak was observed during the culture. This may be because of restricted bacterial growth in the presence of fishes, as the mucus of several fish species, including milkfish, has antimicrobial activity (Austin and McIntosh, 1988; Magariños et al., 1995; Hellio et al., 2002; Tendencia et al., 2006). The PCR screenings showed that the shrimps under culture were negative for viral pathogens, which might have reduced the chance of increase in the load of the opportunistic pathogen like *Vibrios* (Anand Ganesh et al., 2010).

Net income and BCR from both polycultures were not significantly different. However, mullets-shrimp combination resulted in higher net income and BCR, mainly due to increased shrimp production. Economic analysis indicated the viability of both systems and, accounting for all input costs in both the polyculture systems, a significant 26–29% net income margin was obtained. Most of the small and marginal farmers in India including Asia use their own resources such as land, labour, feed materials, and manures derived from their own farm and household wastes; the actual input costs would be lower and net incomes higher for farms where on-farm resources are used (Uddin et al., 2009).

Conclusion

The present findings of total biomass production, net income and water parameter data support the productivity and economic viability of the mullets-tiger shrimp and milkfish-tiger shrimp polyculture systems. Hence, it is suggested that both polyculture systems with the species combinations would be suitable farming options. Furthermore, monitoring the microbial load, good water quality management and continuous monitoring of health of the shrimps by PCR techniques are the key steps to avoid disease outbreaks for successful polyculture. There is scope for economic profitability improvement in these farming systems by stocking larger size fishes and conducting more trials to optimize the stocking density.

Acknowledgements

The authors are grateful to the Director, Central Institute of Brackishwater Aquaculture, Chennai, India and the Officer-in-Charge, Kakdwip Research Centre of CIBA, Kakdwip, West Bengal, India for providing the required facilities to conduct the experiment. Support and help received from the field staff of Kakdwip Research Centre of CIBA are duly acknowledged.

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