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Mixed culture of Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) and flathead grey mullet *Mugil cephalus* (Linnaeus, 1758) in floating cages

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ABSTRACT

The study explored the possibility of integrating the grey mullet *Mugil cephalus* (Linnaeus, 1758) along with Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) in floating cage culture in Godavary Estuary, India. Post-larvae (PL 12) of *L. vannamei* (3 lakhs nos.), were acclimatised and nursed in five hapas for 28 days at a density of 3333 nos. m^{-2}, with survival of 60%. *L. vannamei* juveniles having mean weight of 0.86 g, stocked at a density of 1060 nos. m^{-2}, were cultured along with and without pre-stocked *M. cephalus*, in three floating cages each. Six thousand fry of *M. cephalus* (mean length 4.17 cm; mean weight 1.22 g) were stocked in three cages at uniform density of 23.5 nos. m^{-3}, three months prior to stocking of *L. vannamei*. Shrimps were fed commercial pellets @ 3-8% of body weight, four times daily and harvested after 68 days. Fishes were fed with pelleted feed and after five months attained mean length of 23.7 cm and mean weight of 274.1 g. Survival was 46.4% and the average production obtained was 250.2 kg. At harvest, *L. vannamei* in monoculture system attained mean weight of 13.3 g and in the mixed culture system, average weight obtained for the shrimps was 13.5 g. Survival, feed conversion ratio (FCR) and production of *L. vannamei* from monoculture were 64.7%, 2.0 and 258.9 kg and from mixed culture 76.8%, 1.6 and 311.5 kg respectively. Daily weight increment and specific growth rate (SGR) of *L. vannamei* was 0.18 g and 4.06 for monoculture and 0.19 g and 4.01 for mixed culture, resepectively. Feed conversion, survival and production of *L. vannamei* were significantly ($p<0.05$) better in mixed culture, confirming technical superiority of mixed culture over monoculture.

Keywords: Cage culture, Growth, *Litopenaeus vannamei*, *Mugil cephalus*, Production, Survival

Introduction

Shrimp aquaculture, is expanding at a very rapid pace globally. Among penaeid shrimps, the Pacific white shrimp, *Litopenaeus vannamei* (Boone, 1931), is the most important species farmed worldwide. *L. vannamei*, owing to its high growth rate, euryhaline nature and year round availability of healthy post-larvae (PL), is the preferred crustacean species for coastal aquaculture. The global culture production of *L. vannamei* in 2010 was 2.6 million t, wherein it accounted for 71.8% of the world production of all farmed marine shrimp species and 77.8% of which was produced in Asia (FAO, 2012). India is one of the top producers of farmed shrimp. *L. vannamei* was introduced to Asia for the first time in China in the year 1996 and thereafter farming commenced on a commercial scale. In India, during the last decade, vast expanse of coastal land is devoted to farming of *L. vannamei* which is gradually replacing *Penaeus monodon* culture. *L. vannamei* is generally cultured in coastal ponds constructed in estuarine zones and the construction of ponds causes large scale destruction of ecologically important mangrove population (Primavera, 1994). Intensive shrimp culture practices necessitate use of supplementary feed, fertilisers as well as antibiotics and chemotherapeutants which are ultimately discharged into the surrounding environment, leading to deleterious impacts. Coastal areas or estuaries are characterised by weak currents and less water renewal, resulting in shrimps cultured in coastal ponds being exposed to pollutants because of less water dispersal and ultimately leading to disease outbreaks and mass mortality. This points towards the importance and benefits of shrimp farming in floating cages. In floating cages, water exchange is much higher facilitating availability of good water quality and presence of natural food enables less energy intensive operations with minimal environmental harm (Zarain-Herzberg *et al*., 2006; Chim *et al*., 2008). There are only very few reports available on farming of *L. vannamei* in floating cages. In cage culture of *L. vannamei*, stocking densities varied widely from 10 nos. m^{-2} (Cuvin-Aralar *et al*., 2008) to 2500 nos. m^{-2} (Paquotte *et al*., 1998), with 250 nos. m^{-2} to 500 nos. m^{-2} (Lombardi *et al*., 2006; Zarain-Herzberg *et al*., 2010) being the preferred range.

Culture of finfish along with shrimp in cages considerably increases production by using available ecological resources (culture area and food sources) in a more efficient way. The flathead grey mullet, *Mugil cephalus* (Linnaeus, 1758) being hardy, euryhaline and eurythermal with herbivorous feeding habit, offers excellent scope for integrating with *L. vannamei*. They are filter feeders, feeding predominantly on detritus, diatoms, algae and microscopic invertebrates (McDonough and Wenner, 2003). Juveniles of *L. vannamei* are not consumed by *M. cephalus* and therefore their survival is unaffected by stocking with mullet. Culturing Nile tilapia (*Oreochromis niloticus*) with *L. vannamei* in ponds (Junior *et al*., 2012) and recirculatory tanks (Muangkeow *et al*., 2007; Barraza, 2010) has been observed to be productive. Costa *et al*. (2013) reported on polyculture of *L. vannamei* with *Mugil platanus*. However, till date, no attempt has been made to integrate *L. vannamei* farming with *M. cephalus* in cages. The present study was therefore aimed at examining the technical feasibility of co-culturing *L. vannamei* and *M. cephalus* in floating cages in Godavari Estuary at Narsapur, Andhra Pradesh, India.

Materials and methods

Cage site

The site selected for cage farming was at Narsapur (16°20' 01.8" N; 81°43' 05.3" E) in Godavari Estuary. The site was devoid of strong currents, protected from direct wind and wave action and located away from any source of direct pollution from land. Water depth was 6 m and tidal amplitude was 2 m. Water quality of the site was determined weekly, for a month prior to cage installation and was found to be optimum for cage culture. Salinity of water was 26.5±0.2 ppt, temperature 29.6±0.1°C, pH 7.8±0.1, dissolved oxygen 4.05±0.05 mgl^{-1} and ammonia nitrogen level was 0.007±0.001 mgl^{-1}. The bottom sediment at the site was muddy-sand.

Cage design

Six numbers of circular galvanised iron (GI) cages were fabricated locally . The 6 m dia cage frame was made of 'B' class epoxy painted GI pipe (5 cm dia) and was connected to an outer predator net (braided 60 mm mesh) made of high density polyethylene (HDPE), inner grow-out (8 mm mesh for culture of *M. cephalus* prior to introduction of *L. vannamei* and 2 mm and 4 mm mesh for *L. vannamei* culture during its first and second month and bird nets (80 mm mesh) with a net depth of 3 m. The joints of the cages were double welded for ensuring extra strength. Hand rail at a height of 1 m from the base frames was provided for ensuring safety of the workers and to facilitate routine cage management. Bottom circular GI ballast pipe (5 cm dia) with perforations was provided to keep the nets in exact shape and volume. Velon screens attached to the ballast pipe were provided over the bottom of inner net as substratum for *L. vannamei*. The effective cage volume and surface area were 85 m^3 and 28.3 m^2 respectively. Each GI cage was provided with eight pressurised fiber barrels (200 l capacity) containing 30 psi of air for aiding floatation. Each cage was moored using four galvanised iron poles (10 m height and 7.5 cm dia) each, inserted deep (2 m) into the estuary bottom. The cages were attached to the poles using GI rings and polypropylene ropes of 13 mm dia. Cages were moored 10 m apart from each other to allow sufficient water exchange.

Grow-out rearing of M. cephalus

M. cephalus fry (6000 nos.) measuring 4.17±0.22 cm in length and 1.22±0.13 g in weight, caught from areas adjacent to the cage site by castnet operations in February, 2014 were randomly stocked in equal numbers in three cages, at a stocking density of 23.5 nos. m^{-3}. Fishes were initially fed thrice a day with commercial floating pellets (Growel Feeds Private Ltd., India) having 22% crude protein and 3% crude fat. After two months of grow-out culture, feeding frequency was reduced to twice daily. Fishes were fed @8-12% of body weight, with the ration decreasing with culture duration. Pellets were fed by placing in rectangular polyvinyl chloride (PVC) trays hanged at the bottom from the centre of the cage. Feeding strategy was similar in all the three cages. Fishes were harvested from the cages in the middle of July, 2014 after 5 months of grow-out culture.

Nursery rearing of L. vannamei

Post-larvae (PL 12) of *L. vannamei* (3 lakhs nos.) were procured from a commercial hatchery in Pondicherry, India and were air lifted and brought to the cage culture site at Narsapur during April, 2014. Post-larvae were certified to be produced from specific pathogen free (SPF) broodstock maintained in the same hatchery. The PL were transported in oxygenated polythene bags with crushed ice placed in between the inner and outer covers for maintaining optimum temperature. On reaching the farm site, the PL were acclimatised by placing the polythene bags containing PL in hapas in the estuary for about 15 min. This was followed by sprinkling and slow addition of water from the estuary to the polythene bags before releasing the PL into the hapa in estuary. Five hapas of 1 mm mesh size, measuring 6 x 3 x 2 m were used. Sixty thousand PL were randomly stocked in each hapa at a stocking density of 3333 nos. m^{-2}. Post-larvae were fed crumbled feed (Avanti Private Ltd., India) with 38% crude protein distributed equally over four times a day. After 28 days of nursery rearing, juveniles attained an average weight of 0.86±0.05 g, with an approximate average survival of 60%.

Grow-out rearing of L. vannamei

Around 1.8 lakhs juveniles (0.86±0.05 g) of *L. vannamei* caught from the five hapas were released in May, 2014 randomly into the six cages; three cages pre-stocked with

M. cephalus (referred to as mixed culture or MX) and three cages without pre-stocked fish (referred to as monoculture or MN). All the six cages were stocked equally with 30000 juveniles' each per cage (1060 nos. m^{-2}). *L. vannamei* were fed with commercial sinking pellets (Avanti Private Ltd., India) containing 34% crude protein and 5% crude fat, uniformly four times a day (06.00 hrs, 10.00 hrs, 15.00 hrs and 20.00 hrs). Feed was applied evenly in four feeding trays suspended above cage bottom from four corners of the cage. Feeding regime followed was 6 - 8% of body weight during the first month and 3 - 5% during the second month. Cylindrical PVC pipes were provided as hide-outs for providing shelter for newly moulted shrimps. The shrimps were harvested from all the six cages in middle of July, 2014 after 68 days of grow-out culture.

Cage maintenance, sampling and growth study

The cages were inspected at every 7 days' interval by underwater diving. Clogging by silt and fouling by barnacles were removed at regular intervals. Daily feed intake of *M. cephalus* and *L. vannamei* was assessed from the feed trays and left over feed was collected and weighed. Periodical sampling of *M. cephalus* using hand scoop nets and *L. vannamei* from feed trays were carried out at regular intervals of 15 days to ascertain their health and growth in all the cages. Total length (TL) and body weight (W) of the samples were measured to the nearest 1 mm and 0.01 g, respectively. Water samples were collected fortnightly from the cage area and analysed for temperature, pH, dissolved oxygen, ammonia nitrogen and nitrite nitrogen (APHA, 1998).

Total production and survival of *M. cephalus* and *L. vannamei* were recorded at the end of the culture duration. Important growth parameters *viz*., weight increment per day (g), specific growth rate (SGR) and feed conversion ratio (FCR) were estimated using following formulae:

Weight increment per day (g) = (Final mean body weight - Initial mean body weight) / Number of days

SGR = [(ln final mean body weight - ln initial mean body weight/ Number of days] x 100

FCR = Dry weight of feed provided / Wet weight gain

Statistical analysis

The data were evaluated for normality using the Kolmogorov-Smirnov test and Student's t-test was employed to study the differences of growth parameters, survival and production at 5% probability level.

Results

Cage environment

Water quality parameters monitored during the culture period (Table 1) were well within acceptable limits and indicated that cage culture of *M. cephalus* and *L. vannamei* has not adversely influenced the environment.

Table 1. Water quality parameters observed during the culture period

Parameters	Range	Mean±SE
Salinity (ppt)	17.0 - 28.0	23.1±0.9
Temperature (°C)	29.6 - 31.4	30.6±0.3
pH	7.4 - 8.2	7.9±0.1
Dissolved oxygen (mg l^{-1})	3.6 - 4.2	3.9±0.1
Ammonia nitrogen (mg l^{-1})	0.005 - 0.012	0.008±0.001
Nitrite nitrogen (mg l^{-1})	0.011 - 0.020	0.015±0.002

Grow-out rearing of M. cephalus

M. cephalus fry reached 23.7±0.4 cm in length and 274.1±9.6 g in weight after five months of culture in cages. The survival rate was 46.4±1.5% and average production from each cage was 250.2±14.0 kg (2.9±0.2 kg m^{-3}). Details of length, weight and growth parameters at fortnightly intervals are given in Table 2. Daily weight increment and SGR at the time of harvest was 1.8±0.1 g and 3.6±0.0 respectively.

Grow-out rearing of L. vannamei

Juveniles of *L. vannamei* in MN, reached 11.9±0.2 cm and 13.3±0.5 g after 68 days of culture, while in MX, length

Table 2. Length-weight and growth performance (Mean±SE) of *M. cephalus* in cage

Days of culture	Length (cm)	Weight (g)	Weight increment per day (g)	Specific growth rate
15	7.2±0.2	5.6±0.4	0.29±0.02	10.20±0.07
30	10.9±0.2	17.1±1.5	0.53±0.05	8.80±0.04
45	12.8±0.2	36.3±1.2	0.78±0.02	7.56±0.10
60	14.7±0.3	66.0±4.2	1.08±0.07	6.66±0.02
75	16.1±0.2	95.8±4.3	1.26±0.06	5.83±0.05
90	17.8±0.3	129.8±4.2	1.43±0.05	5.19±0.05
105	18.9±0.2	160.4±7.3	1.52±0.07	4.65±0.03
120	20.5±0.3	197.7±9.8	1.64±0.08	4.25±0.02
135	22.5±0.4	243.5±11.5	1.79±0.08	3.93±0.02
150	23.7±0.4	274.1±9.6	1.82±0.06	3.61±0.03

[a]Growth performance on each day of culture was calculated from 0 day

and weight attained were 12.0±0.3 cm and 13.5±0.2 g respectively. Average length and weight recorded fortnightly for *L. vannamei* in MN and MX are summarised in Table 3 and details of survival, FCR and production of *L. vannamei* in MN and MX are presented in Table 4. FCR was significantly ($p<0.05$) higher and survival as well as production were significantly ($p<0.05$) lower in MN, as compared to MX.

Daily weight increment and SGR on days 15, 30, 45, 60 and 68 are presented in Table 5. There was no significant ($p>0.05$) difference in daily weight increment and SGR recorded for *L. vannamei,* between MN and MX. Daily weight increment and SGR at harvest was 0.18±0.01 g and 4.06±0.04 for MN and 0.19±0.00 g and 4.01±0.03 for MX respectively. SGR was higher the first 15 days of culture and decreased gradualy towards the end. On the contrary, weight increment per day was higher during the later phase of culture.

Discussion

The cage design and mooring system adopted in the present study were found to be suitable for culture of *L. vannamei* and *M. cephalus*. Earlier studies on cage cultured *L. vannamei*, used hapa net cages (Cuvin-Aralar *et al*., 2008), rectangular PVC cages (Paquotte *et al*., 1998; Lombardi *et al*., 2006; Zarain-Herzberg *et al*., 2010), circular HDPE cages (Zarain-Herzberg *et al*., 2010) or rectangular HDPE cages (Sivanandavel and Soundarapandian, 2013). This is the first report on culture of *L. vannamei* in GI floating net cages. There was no disease or water quality problems observed during the culture period, as evident from the regular sampling. Water quality parameters from cage area during culture were within the limits as stated by Boyd and Tucker (1998). Similar values of water quality were observed in cage cultured *L. vannamei* from other locations (Zarain-Herzberg *et al*., 2010; Ray *et al*., 2011; Sivanandavel and Soundarapandian, 2013).

Polyculture of *M. platanus* with *L. vannamei* in earthen ponds at densities of 0.67 nos. m^{-2} for 79 days recorded 82 to 84% survival and SGR of 3.69 to 3.99 (Costa *et al*., 2013). In comparison, *M. cephalus* reared in cages in the present study at much higher stocking density of 23.5 nos. m^{-3} recorded higher weight increment (1.3 g day^{-1}) and SGR (5.8) on day 75. Feeding with artificial diet coupled with optimum water quality resulted in improved growth performance of *M. cephalus* in cages.

Table 3. Length and weight (Mean±SE) of *L. vannamei* in monoculture and mixed culture

Days of culture	Monoculture		Mixed culture	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)
0	3.3±0.0	0.8±0.0	3.3±0.1	0.9±0.0
15	5.9±0.1	2.2±0.2	5.9±0.2	2.2±0.1
30	8.2±0.1	4.6±0.3	8.1±0.2	4.6±0.1
45	10.0±0.1	8.0±0.4	10.0±0.2	8.1±0.2
60	11.3±0.1	11.7±0.6	11.3±0.2	11.6±0.4
68	11.9±0.2	13.3±0.5	12.0±0.3	13.5±0.2

Table 4. Survival, FCR and production (Mean±SE) of *L. vannamei* in monoculture and mixed culture

	Monoculture	Mixed culture
Survival %	64.7±1.7[a]	76.8±3.0[b]
FCR	2.0±0.1[a]	1.6±0.0[b]
Production (kg and kg m^{-2})	258.9±9.0[a] and 9.1±0.3[a]	311.5±17.1[b] and 11.0±0.6[b]

[a]Mean values with different superscripts between columns in each row indicate significant ($p<0.05$) differences (between monoculture and mixed culture)

Table 5. Weight increment and specific growth rate (Mean±SE) of *L. vannamei* in monoculture and mixed culture

Days of culture	Weight increment per day (g)		Specific growth rate (SGR)	
	Monoculture	Mixed culture	Monoculture	Mixed culture
15	0.09±0.02[a]	0.09±0.01[a]	6.33±0.64[a]	6.07±0.26[a]
30	0.12±0.01[a]	0.12±0.00[a]	5.63±0.18[a]	5.48±0.09[a]
45	0.16±0.01[a]	0.16±0.00[a]	4.99±0.08[a]	4.92±0.05[a]
60	0.18±0.01[a]	0.18±0.01[a]	4.39±0.07[a]	4.30±0.05[a]
68	0.18±0.01[a]	0.19±0.00[a]	4.06±0.04[a]	4.01±0.03[a]

[a]Mean values for each growth parameter with different superscripts between columns in each row, for each day indicate significant ($p<0.05$) differences (between monoculture and mixed culture)

[b]Increment and SGR on each day of culture was computed from 0 day

Growth of *L. vannamei* is sensitive to cultivation density during the nursery stage (Moss and Moss, 2004). Lower rearing densities ranging from 500 to 1600 nos. m^{-2} during nursery phase before cage stocking were reported by earlier authors (Paquotte *et al*., 1998; Lombardi *et al*., 2006; Cuvin-Aralar *et al*., 2008; Zarain-Herzberg *et al*., 2010). Zarain-Herzberg *et al*. (2010) reported survival of 65.8 to 76.7% and 1.2 g weight increment after rearing post-larvae for 38 days. The same authors observed higher survival and growth at lower stocking density. In the present study, with much higher stocking density, similar growth of *L. vannamei* post-larvae was observed. This could be attributed to the fact that post-larvae were fed four times daily with crumbled feed containing 38% crude protein.

Production of farmed aquatic species in cages appears to be far superior when compared to farming in ponds and tanks. The natural and continuous renewal of water in cages provides optimum water quality in and around cage sites. Water quality is similar to that of the natural environment of the species. Bio-fouling on net coupled with continuous supply of phytoplankton and zooplankton, supplements the nutritional deficiencies in the pelleted feed (Paquotte *et al*., 1998). *L. vannamei* were reared in marine cages (Lombardi *et al*., 2006; Zarain-Herzberg *et al*., 2010) at densities ranging from 250 to 500 nos. m^{-2}, while in the present study, it was reared in estuary at density of 1060 nos. m^{-2}. Daily growth increment and survival observed in marine cages (Lombardi *et al*., 2006; Zarain-Herzberg *et al*., 2010) varied from 0.12 to 0.27 g and 70 to 80% respectively. Similar growth increments of 0.18 to 0.19 g per day and survival of 64.7 to 76.8% were obtained at higher stocking density, in the present study in Godavary Estuary. FCR was similar to earlier reports (Paquotte *et al*., 1998; Lombardi *et al*., 2006; Cuvin-Aralar *et al*., 2008; Zarain-Herzberg *et al*., 2010) from cage culture. Growth performance, survival and feed conversions of cage cultured *L. vannamei* in estuarine and marine environment are similar. However because of higher density used in the present study in estuary, production of *L. vannamei* was higher (9.1 kg - 11.0 kg m^{-2}) than that reported earlier from both marine and low saline cages (0.8 - 8.0 kg m^{-2}) (Paquotte *et al*., 1998; Lombardi *et al*., 2006; Cuvin-Aralar *et al*., 2008; Zarain-Herzberg *et al*., 2010; Sivanandavel and Soundarapandian, 2013). The present study reports the highest production of *L. vannamei* obtained till date from cage farming. The use of cylindrical PVC pipes as hide-outs for shelter of newly moulted shrimps reduced cannibalism with subsequent higher survival, thus enabling culture at high density. Moss and Moss (2004) and Arnold *et al*. (2006) reported on the use of artificial substrates for increasing survival and negating the effect of density in shrimp culture. The use of velon screen as substrate at the bottom could have contributed to the success of high density farming in the present study. Increments in weight increased with advancement of culture. SGR decreased with increase in weight of shrimp. Jobling (1994) reported on an inverse relationship between SGR and weight, which are in full agreement to the present study.

Integrating species from different trophic levels or species having different feed preferences in the same aquatic system maximises resource utilisation and reduces adverse environmental impacts (Troell *et al*., 2003; Yuan *et al*., 2010). Therefore, exploiting differential feeding behaviour and stocking species occupying different spatial niches enables efficient utilisation of space and natural food resources. The same concept was attempted in the present study, by stocking two complementary species occupying inferior trophic levels (herbivore and omnivore), *L. vannamei* and *M. cephalus*, for increasing production from cage. *M. cephalus* obtain majority of their food from the water column (Cardona and Castello, 1994), whereas *L. vannamei* is a benthic feeder. Survival, feed conversions and production of *L. vannamei* was significantly better in MX than in MN. However, weight increment and SGR did not vary. Similar to the present observation, Junior *et al*. (2012) stated that fish and *L. vannamei* growth rates are not inter-dependent, and they do not interfere with the development of each other in mixed culture systems. It is evident that with similar growth rates in MN and MX, production was higher in MX because of higher survival. With similar feeding ration, lower FCR in MX than in MN is because of higher survival in MX, resulting in better feed conversions. Fish, as they are neither susceptible nor carriers of shrimp viruses, helps to prevent transmission of viruses (Yi *et al*., 2002; Cruz *et al*., 2008). Higher survival of *L. vannamei* in MX could also be attributed to inhibiting effect of mullets on certain pathogenic microorganisms. The slime of mullets produces enzymes that can inhibit the growth of pathogenic Gram-negative bacteria and support growth of probiotic Gram-positive bacteria, benefitting *L. vannamei*. Similar observations on higher survival of shrimps, when co-cultured with tilapia were reported by Yi *et al*. (2002) and Cruz *et al*. (2008). "Detrital rain" from fecal matter of *M. cephalus* contributed to higher food availability and better performance of *L. vannamei* in MX (Yi *et al*., 2002; Yuan *et al*., 2010). Similar, higher survival and net shrimp yield in MX than in MN has been widely reported by various authors (Akiyama and Anggawati, 1998; Tian *et al*., 2001; Jana *et al*., 2007) and they opined that better water quality in MX to be the contributing factor when compared to MN. In contrary, Costa *et al*. (2013) observed deteriorated growth of *L. vannamei* when cultured with *M. platanus* in earthen ponds. According to them, *L. vannamei* grew 18.8% more in the absence of *M. platanus*, while *M. platanus* increased by 27.3% in mixed culture. They attributed reduced growth of *L. vannamei* in mixed culture to competition for food with mullets, as both the species were in the same environment and had free access to the same feed. However in the present

study, since both *L. vannamei* and *M. cephalus* were fed separately and optimally, there was no contest for food and growth was similar in MN and MX.

Production of *L. vannamei* in MX was significantly higher than in MN. Performance indicators in MX firmly confirm its technical feasibility, since both species complemented each other and did not interfere in their growth. Mixed culture of *L. vannamei* at high density with *M. cephalus* permitted optimal utilisation of the available space inside cages, thus contributing substantially in improving the technical and the economic aspects of shrimp farming in open waters. However, caution needs to be exercised on issues of potential biosecurity, caused by escape of *L. vannamei* into open waters as it is an exotic species and can have deleterious impacts on the indigenous shrimp population in the region, threatening biodiversity. The present findings indicate feasibility of mixed culture of compatible species in cages using resource-efficient approach. Optimisation and inclusion of other commercially important resources are future researchable areas.

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