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Structure and seasonal dynamics of penaeid shrimp post-larvae and juvenile assemblage in Alamparai estuary, Southeast coast of India

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Original Article

Abstract

The structure and seasonal dynamics of penaeid shrimp post-larvae and juvenile assemblage in the Alamparai estuary were studied for two years from April 2012 to March 2014 concerning environmental characteristics such as rainfall, water temperature, salinity, pH, dissolved oxygen, nitrite, phosphate and silicate. A total of six commercially important species of penaeid shrimps *viz., Penaeus indicus, P. monodon, P. semisulcatus, Metapenaeus dobsoni, M. monoceros* and *M. brevicornis* were recorded. The post-larvae and juveniles of *P. indicus* were the most abundant throughout the year, with two peaks post-monsoon (226.3±154.4 N/m^2) and pre-monsoon (136.7 ± 93.1 N/m^2) at all stations. *M. brevicornis* post-larvae and juveniles were dominant in post-monsoon (140.7±89.7 N/m^2) at all stations. Both *P. monodon* (120.0±102.2 N/m^2) and *P. semisulcatus* (29.3±17.2 N/m^2) were predominant in monsoon season. The peak abundance of *M. monoceros* post-larvae and juveniles was recorded in pre-monsoon (40.7±33.6 N/m^2), whereas that of *M. dobsoni* was predominant in summer (40.3±45.1 N/m^2). Moreover, canonical correspondence analysis indicated that nitrite, phosphate and silicate, along with water temperature, pH, salinity and dissolved oxygen, were the main driving forces for these temporal variations in species distribution and community composition of penaeid shrimp post-larvae and juveniles. Finally, correlation analysis showed a significant correlation with water temperature, dissolved oxygen, salinity and silicate.

Keywords*: Shrimp post-larvae, juveniles, seasonal, environmental variables, Alamparai estuary*

Introduction

Estuaries have been aptly referred to as the "doorways between oceans and land masses". Although the Indian mainland coastline is mostly even, several river systems with their estuaries, extensive backwaters, mangroves, shell beds and coastal lagoons provide several hectares of water surface that are predominantly brackish (Tampi, 1967). The fisheries of estuaries and the brackish water are mainly dependent on the ingress and egress of larvae and juveniles of shrimps (Menon and Raman, 1961; Rajyalakshmi, 1961; Ramamurthy, 1972; Sampson Manickam and Sreenivasagam, 1972; Sudhakara Rao, 1975, 1990; Lalithadevi, 1988; Kurup *et al.,* 1993; Kathirvel, 2001). Determining the spatial and temporal distributions of shrimp post-larval assemblages and the physical mechanism that shapes them, can provide insights into the patterns that structure adult populations (Fuiman and Werner, 2002). Shrimp larval assemblage dynamics are highly influenced by physico chemical parameters and often reflect changes in the estuarine environment. This makes the early life stages of shrimps and fishes uniquely susceptible to environmental perturbations, which impact adult recruitment, food web dynamics, and ecosystem services (Zhang *et al.,* 2021).

Brackish water impoundments serve as nursery grounds for several economically important species of shrimps (Mohamed and Vedavyasa Rao, 1971; Wickens, 1976; Achuthankutty and Nair, 1980; George and Suseelan, 1982; Sambandam *et al.,* 1982; Achuthankutty, 1987; Gunaga *et al.,* 1989; Sambandam, 1994; Mohan *et al.,* 1995; De and Sinha, 1997). It is a well-known fact that shrimps breed and spawn in the sea and the young ones of less euryhaline species migrate towards coastal waters, estuaries and brackish waters for feeding and growth and then return to the sea for reproduction (Mohamed and Vedavyasa Rao, 1971; Manja Naik *et al.,* 2009). Earlier two studies from the Alamparai region were related to shrimp seed resources from the nearby Marakkanam estuary (Bose and Venkatesan, 1982) and jellyfish processing at Alamparai Kuppam (Kuthalingam *et al.,* 1989). The present investigation aimed to study the composition and seasonal distribution of penaeid shrimp post-larvae and juveniles in the Alamparai estuary concerning physicochemical characteristics.

Material and methods

Study area

Alamparai estuary (Yedayanthittu), a small brackish water system (12°12'- 12°15'N and 70°56' – 80°0' E) on the north-eastern part of Kazhiveli Wetland, is important from the focal point of fishery and seed resources and constituted the lifeline of the local economy. The Alamparai estuary is part of a system of backwaters on the east coast of India linked with Pulicat Lake by the historical Buckingham canal, which runs parallel to the coast from Nellore in the North to Parangipettai in the south (Scott, 1989). The estuary is constantly subjected to long-term fluctuations in salinity with the incursion of seawater at every high tide and with the flow of fresh water from the river or by heavy rainfall. Alamparai estuary is 16 km long with a width of 157 m at its widest point near the mouth and 70 m in its upper reaches, with depths varying from 2 m in the lower reaches to 3.4 m in the upper reaches. The Alamparai estuary drains a catchment area of 176 km^2. The estuary runs for about 16 km from Kanthadu, Vandipalayam and Chettikulam villages from little north of the Marakknam Road Bridge to the point of the confluence with the Bay of Bengal at Alamparai port, Kanchipuram District, Tamil Nadu (Silambarasan, 2018) (Fig. 1).

Post-larval sampling

The present investigation collected shrimp post-larvae and juveniles from April 2012-March 2014 from the Alamparai estuary. For the sampling process, three stations were chosen based on differences in physical characteristics (position, types of bottom and water depth). Station I was fixed in the mouth of the estuary to study the influence of neritic waters on the density of post-larval abundance, Station II was fixed at a historical place in Buckingham canal from admixes with Alamparai estuary, 2 km away from station I and station III was fixed at mangrove area situated in saltpans and adjacent Kaliveli (Kazhuveli) wetland and 4 km away from the

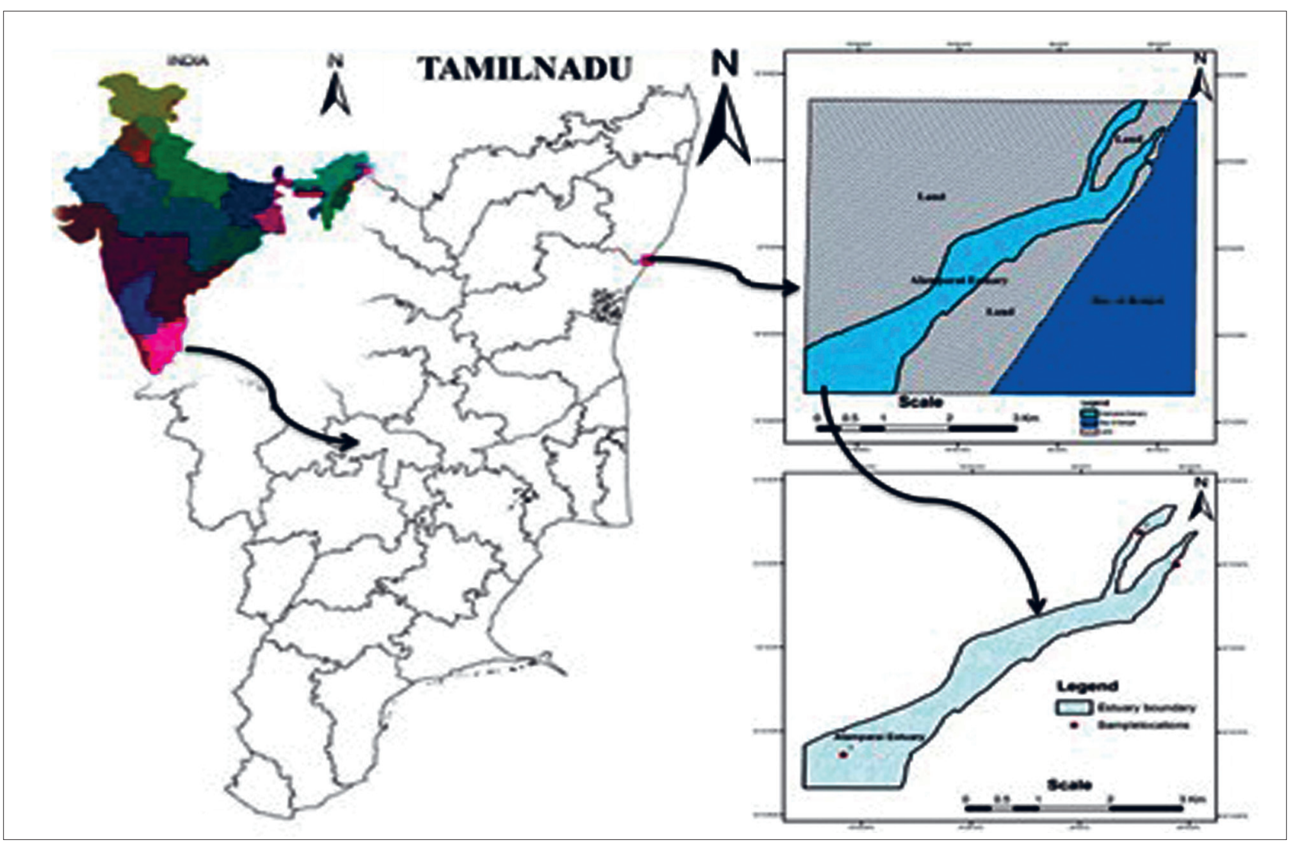

Fig. 1. Map showing the collection sites of Alamparai estuary. (*indicates that sampling stations 1. Station-I (Barmouth), Station-II (Buckingham canal) and Station-III (Mangrove area)

Station I. A rectangular drag net with a 2 m length, 1 m depth including cod-end and a mesh size of 2 mm was used for sampling. The vertical net is supported by bamboo split poles (1.6 m long x 0.6 m wide), and a plastic bucket was attached at the cod end for collecting sample materials. A synthetic monofilament net material (high-density polyethene) with knot-less webbing was used to make the sampling net. Samples were collected during the full and new moon periods seasonally once at a time. For each sampling, the net was dragged, starting from shallow waters and continuing along the adjacent sand-mud bank, covering a total area of 10 m^2. Usually, four replicates were done in each netting time. The catches were cleaned on shore for twigs, leaves, and large specimens and immediately preserved in 5% formalin mixed with estuarine water. In the laboratory, the number of all penaeid species was recorded. Specimens of *P. indicus, P. monodon, P. semisulcatus, M. dobsoni*, *M. monoceros* and *M. brevicornis* were identified by examining external morphological characters, body shape and body proportions (CIFRI, 1962; FAO, 1974; CMFRI, 1978; Paulpandian and Ramsamy, 1991; Muthu *et al.,* 1992).

Rainfall data for the Alamparai estuary (Marakkanam region) were obtained from the Tamil Nadu Water Testing House, Taramani, Chennai. Water temperature was measured in the field using a good-grade mercury-filled centigrade thermometer. Water samples were collected with 5 ltr Polyethylene bottles. Winkler's titrimetric method (Grasshoff, 1983) was followed to estimate Dissolved oxygen (DO). Salinity was measured using the WTW 330i probe with an accuracy of ±1 digit and a resolution of 0.1 mS. pH measurement was carried out by a pH meter (WTW 330i probe, Germany) with a resolution of 0.01. To analyse nutrients, surface water samples were collected in clean polyethene bottles and kept in an ice box and transported immediately to the laboratory. The water samples were filtered using a Millipore filtering system (MFS) and analyzed for dissolved phosphate, nitrite and silicate by adopting the standard methods described by Strickland and Parsons (1972).

Statistical analysis

In the present study, species diversity was assessed using three different indices, *viz.,* Shannon-Weiner diversity, Evenness and Species richness indices in spatial and temporal patterns. Shannon-Weiner diversity index [H] (Shannon and Weiner, 1963), Margalef index (d) [D= (S/1) = log (N)] (Margalef, 1958) and Pielou evenness (*J'*) $J=H^1/\log_2{}^S$ were computed. Before analyses, data were pretreated, standardized and then overall transformed using the fourth root method. A single linkage Bray-Curtis cluster analysis was constructed to determine the similarity in their diversity and abundance distribution in shrimp post-larvae and juveniles in the Alamparai estuary using Primer version 6.1.5. (Clarke and Warwick, 2001). Analysis of similarity (ANOSIM) was used to determine whether the assemblage pattern separated by cluster dendrogram differed significantly. Once the significant difference was found, a similarity percentage (SIMPER) was used to examine which species contributed most to the difference.

To examine the effect of environmental variables including rainfall, water temperature, salinity, pH, dissolved oxygen, nitrite, phosphate and silicate on six shrimp post-larvae and juveniles, Canonical correspondence analysis (CCA) was used (CANOCO for windows version 4.5 software (Ter Brake and Smilauer, 2002). The optional used for CCA was bi-plot scaling with a focus on inter-species distance. A Monte Carlo test (199 permutations) was run to detect a significant pattern. The graphical package Sigma Plot version 11.0 was used to construct graphs.

Results

Environmental variation

Total annual rainfall recorded from the Alamparai estuary was 1607 mm (April 2012 -March 2013) and 960.2 mm (April 2013-March 2014). The maximum monthly rainfall of 70.4 mm

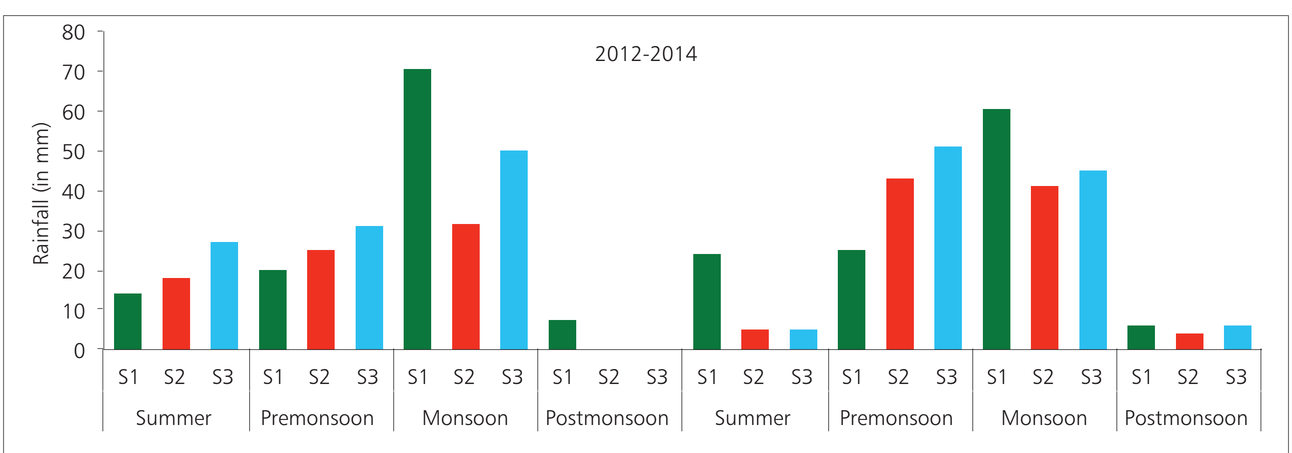

Fig. 2. Seasonal variations of rainfall (mm) at three stations (S1, S2 and S3)

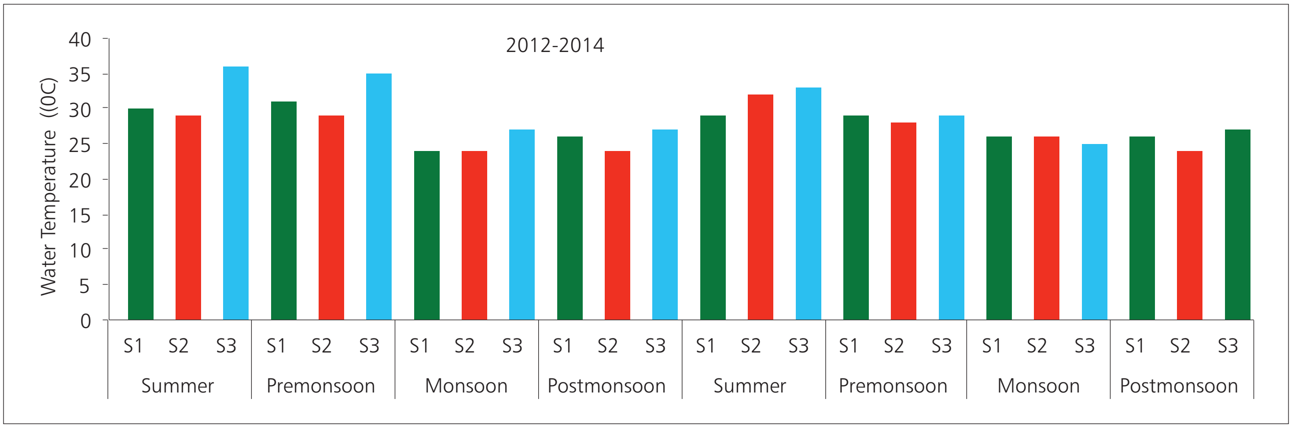

Fig. 3. Seasonal variations of surface water temperature (°C) at three stations (S1, S2 and S3)

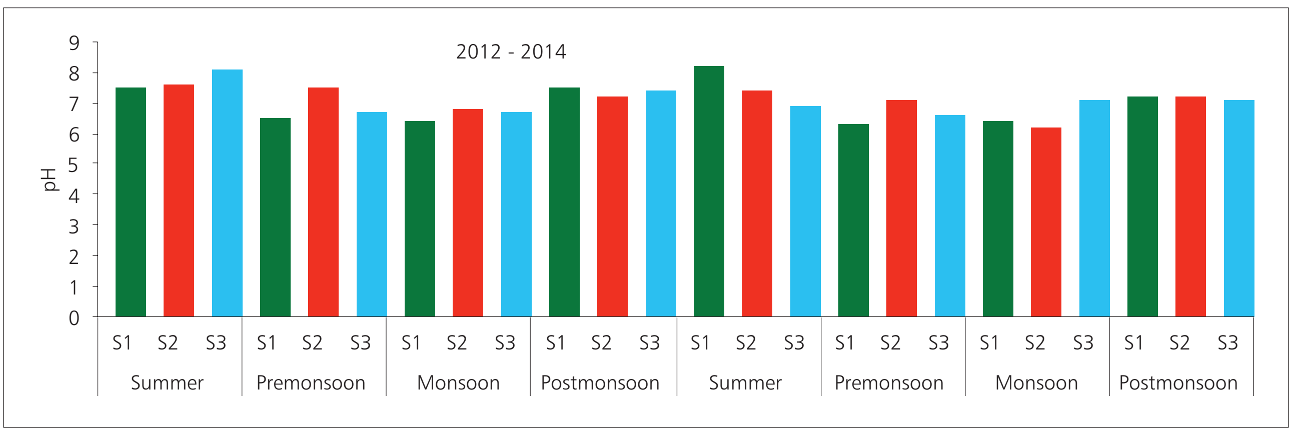

Fig. 4. Seasonal variations of pH at three stations (S1, S2 and S3)

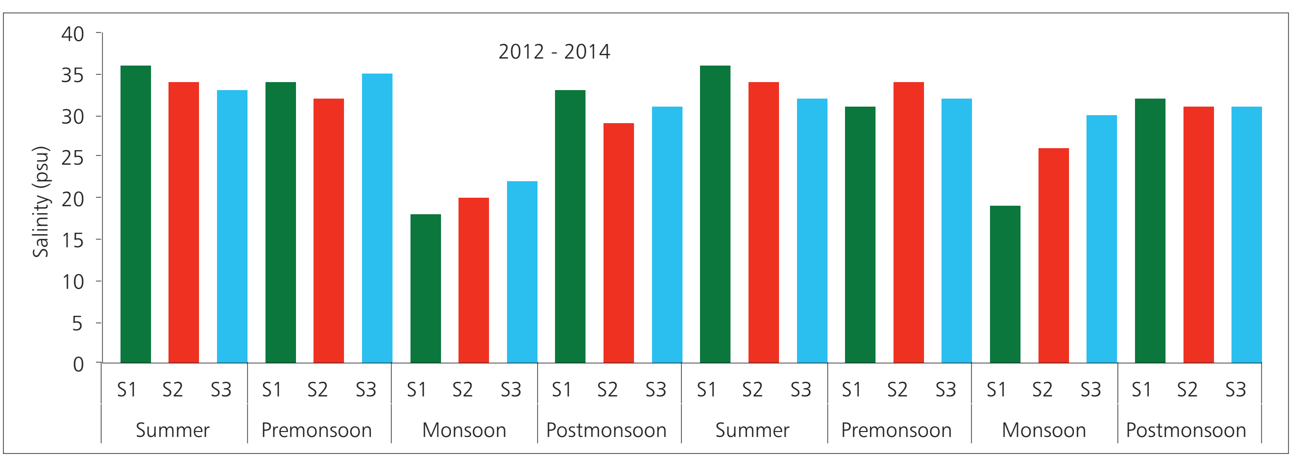

Fig. 5. Seasonal variations of salinity (PSU) at three stations (S1, S2 and S3)

was recorded during the monsoon season (November 2012), and the minimum rainfall of 4.0 mm was recorded during post monsoon season (February 2014). The monthly observed average rainfall was higher in 2012-13 compared to 2013-14 (Fig. 2).

The water temperature ranged between 24.0 °C and 36.0 °C. The minimum water temperature (24.0 °C) was recorded during the monsoon season (November 2012) at station I, and the maximum (36.0 °C) was recorded during the summer season (May-2012) at station III (Fig. 3). In general, all three stations showed similar seasonal variations. Hydrogen ion concentrations (pH) of water varied from 6.2 to 8.2. Minimum values (6.2) of pH were registered in the monsoon season (December 2013) at station II, and

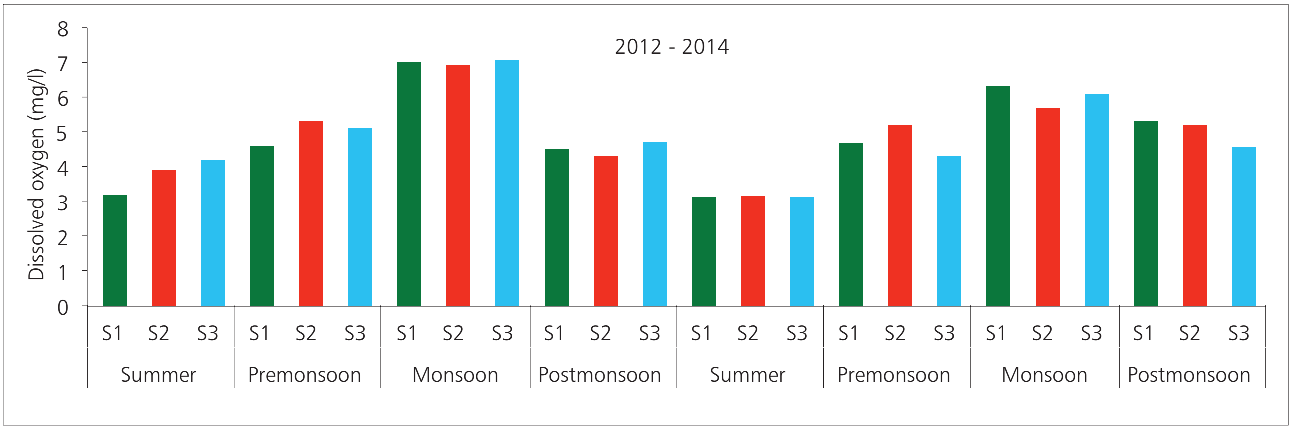

Fig. 6. Seasonal variations of dissolved oxygen (mg/l) at three stations (S1, S2 and S3)

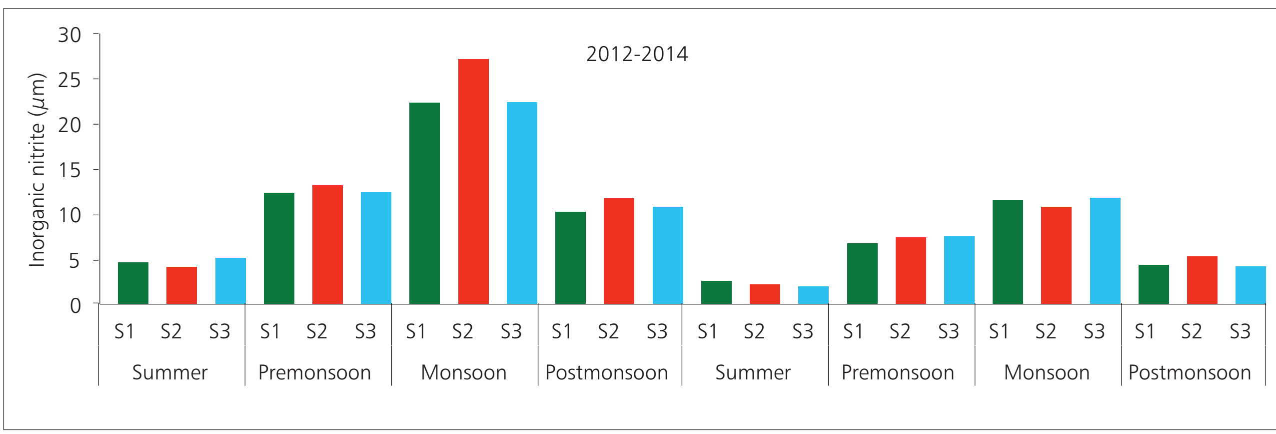

Fig. 7. Seasonal variations of Nitrite (µM) at three stations (S1, S2 and S3)

maximum values (8.2) were recorded in the summer season (May-2013) at station III (Fig. 4).

The variation in salinity and dissolved oxygen concentrations are reflected in pH. A marked seasonal change in salinity was observed throughout the study period. Salinity ranged from 18 to 36 PSU. Low salinity (18 PSU) was recorded during monsoon season (December-2012) at station I, and slowly increased during post-monsoon and attained a maximum (36 PSU) during summer (April 2012) at station II (Fig. 5).

During the present study, a wide fluctuation in dissolved oxygen content was observed. It ranged from 3.2 to 7.07 mg l^{-1}. The less (3.2 mg l^{-1}) value of dissolved oxygen content was recorded during the summer season (May-2012) at station I, and the high value (7.07 mg l^{-1}) was recorded during the monsoon season (December-2012) at station III (Fig. 6).

The nitrite concentration varied from 1.97 to 27.14 µM. The minimum (1.97 µM) was recorded during the summer season (May-2012) at station III, and the maximum (27.14 µM) during the monsoon season (December-2012) at station III (Fig. 7). Phosphate levels varied from 2.92 to 11.91 µM. The lesser (2.92 µM) value was recorded during the summer season (May-2013) at station II, and the higher value (11.91 µM) was observed during the monsoon season (December-2012) at station III (Fig. 8). The observed silicate value ranged from 12.36 to 54.76 µM l^{-1}. The lowest value (12.36 µM l^{-1}) was observed during the pre-monsoon season (September 2013) at station II, and the peak value (53.82 µM l^{-1}) was observed in the monsoon (December-2013) (Fig. 9).

Catch composition

During the study period, a total of six species of shrimp post-larvae and juveniles were recorded *viz.*, *P. indicus* H. Milne Edwards, *P. monodon* Fabricius, *P. semisulcatus* De Haan, *M. dobsoni* (Miers), *M. monoceros* (Fabricius) and *M. brevicornis* (H. Milne Edwards). The post-larvae of *P. indicus* (41%) were predominant in the samples throughout the study period,

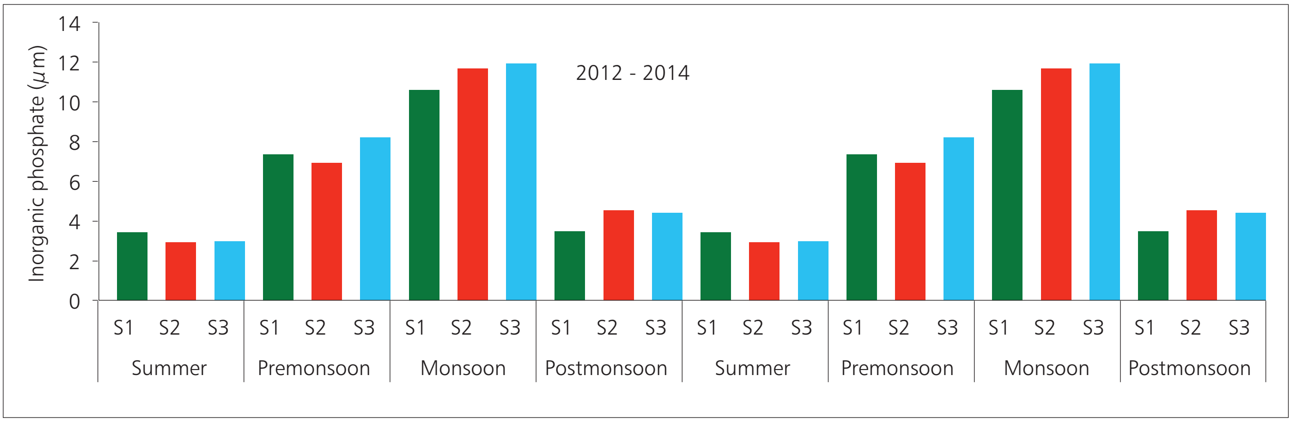

Fig. 8. Seasonal variations of Phosphate (µM) at three stations (S1, S2 and S3)

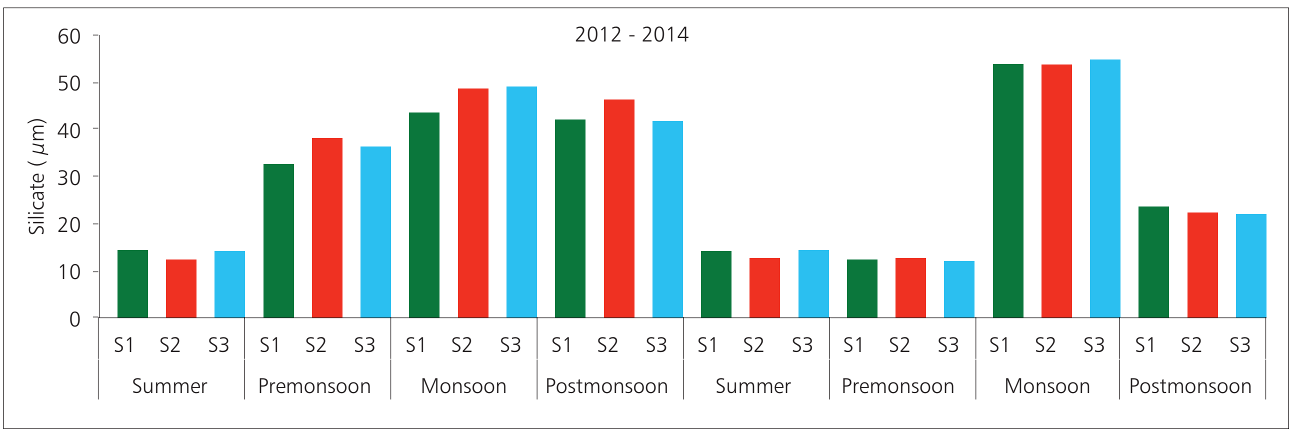

Fig. 9. Seasonal variations of silicate (µM) at three stations (S1, S2 and S3)

followed by *M. brevicornis* (19%), *P. monodon* (18%), *M. dobsoni* (7%), *M. monoceros* (8%) and *P. semisulcatus* (7%).

Spatial and temporal variation

P. indicus was the most abundant species, (41%) of the total population. The post-larvae and juveniles of the species were collected throughout the year with two peak periods (post-monsoon and premonsoon). The mean total density was significantly different between seasons; the maximum mean density was recorded in post-monsoon (226.3±154.4 N/m^2), followed by premonsoon (136.7 ± 93.1 N/m^2), summer (16.3±12.1 N/m^2) and monsoon (12.0±8.19 N/m^2). The station-wise mean density observed is Station-1 (82.75±87.5 N/m^2), Station-II (39.75±42.4 N/m^2) and Station III (171.0±180.1 N/m^2). Thus Station III recorded more numbers, which may perhaps be due to the mangroves around that station. *P. monodon* post-larvae and juveniles showed distinct variation and were dominant during monsoon (120.0±102.2 N/m^2), followed by post-monsoon (38.0±32.7 N/m^2), summer (5.0±20.9 N/m^2) and premonsoon (0.7±1.2 N/m^2). The mean density of post-larvae and juveniles was more abundant in station III (81.7±92.0 N/m^2), followed by station-1 (44.2±63.7 N/m^2) and station II (5.7±5.1 N/m^2). *P. semisulcatus* post-larvae and juveniles are available plentifully in the seagrass and algal beds. The maximum abundance of *P. semisulcatus* was recorded in monsoon (29.3±17.2 N/m^2) and minimum at premonsoon (1.3±1.5 N/m^2). The maximum abundance was at Station III (30.7±27.1 N/m^2) and the minimum at Station II (9.5±8.7 N/m^2). The greater abundance of *M. dobsoni* was recorded in summer (40.3±45.1 N/m^2) and less in premonsoon (9.0±4.0 N/m^2). Post-larvae and juveniles were more abundant in station III (38.0±36.9 N/m^2) and less abundant in station II (8.0±1.2 N/m^2). The abundance of *M. monoceros* post-larvae and juveniles ranged from 3.0 to 40.7 N/m^2. The higher abundance was recorded in premonsoon (40.7±33.6 N/m^2), and less in monsoon (3.0±2.6 N/m^2). The highest mean density was recorded in Station III (33.7±34.1 N/m^2) and the lowest mean density, was at station II (5.7±6.8 N/m^2). *M. brevicornis* was the second most abundant species, (19%) of the total population. *M. brevicornis* post-larvae ranged from 3.7 to 140.7 N/m^2). The maximum abundance was recorded in post-monsoon (140.7±89.7 N/m^2) followed

Table 1. Seasonal variation and mean density (N/m^2) of Shrimp post-larvae and juveniles in the Alamparai estuary

Species	Summer		Pre-monsoon		Monsoon		Post-monsoon	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P. indicus	16.3	12.1	136.7	93.1	12.0	8.19	226.3	154.4
P. monodon	5.0	20.9	0.7	1.2	120.0	102.20	38.0	32.7
P. semisulcatus	28.0	26.3	1.3	1.5	29.3	17.21	9.3	5.5
M. dobsoni	40.3	45.1	9.0	4.0	11.0	4.58	17.0	12.5
M. monoceros	23.7	17.2	40.7	33.6	3.0	2.65	5.7	4.9
M. brevicornis	6.0	6.6	3.7	3.5	29.3	12.01	140.7	89.7

by the monsoon (29.3±12.01 N/m^2), summer (6.0±6.6 N/m^2) and pre-monsoon season (3.7±3.5 N/m^2). Station-wise, the mean density of *M. brevicornis* post-larvae ranged from 14.2 to 68.2 N/m^2. The highest mean density was recorded in Station III (68.2±97.0 N/m^2), followed by Station-1 (52.2±79.4 N/m^2) and Station II (14.2±18.9 N/m^2). The density at station III was significantly higher than the other two stations (Tables 1 and 2; Figs. 10 and 11). In the present result, seasonal distribution was not significantly varied ($F=3.8$; $P=0.46$), as indicated by the ANOVA test. Station-

Table 2. Station wise mean density (N/m^2) of shrimp post-larvae and juveniles in the Alamparai estuary

Species	Total	Station-1		Station-2		Station-3	
		Mean	SD	Mean	SD	Mean	SD
P. indicus	1174	82.75	87.5	39.75	42.4	171	180.1
P. monodon	527	44.25	63.7	5.75	5.1	81.75	92.0
P. semisulcatus	204	10.75	8.1	9.5	8.7	30.75	27.1
M. dobsoni	232	12.0	6.3	8.0	1.2	38.0	36.9
M. monoceros	219	15.25	12.0	5.75	6.8	33.75	34.1
M. brevicornis	539	52.25	79.4	14.25	18.9	68.25	97.0
Total	2895	36.21	38.11	13.83	15.21	70.58	58.65

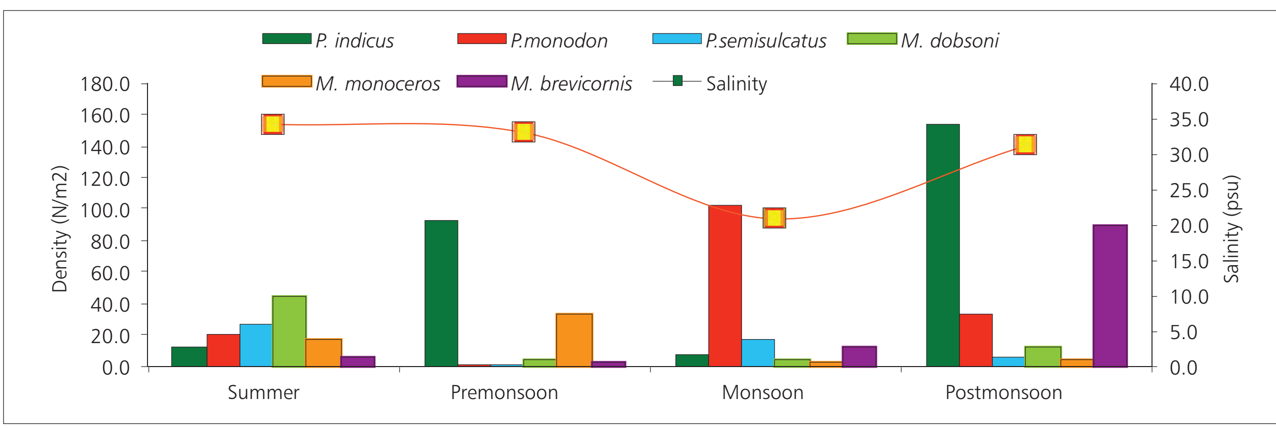

Fig. 10. Seasonal variation and mean density (N/m^2) of shrimp post-larvae and juveniles with salinity in the Alamparai estuary.

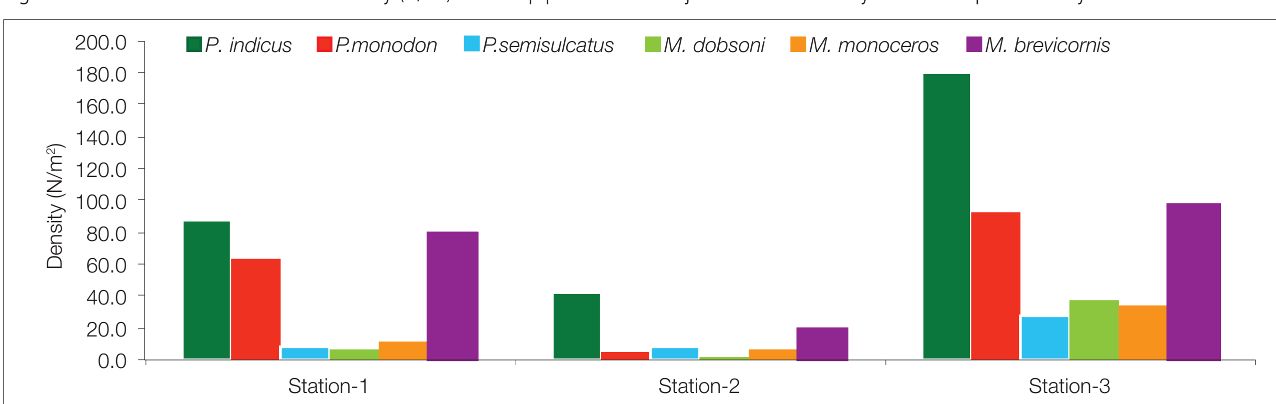

Fig. 11. Station-wise mean density (N/m^2) of Shrimp post-larvae and juveniles in the Alamparai estuary

wise, the highly significant effect of shrimp post-larvae and juvenile distribution existed, as indicated by the ANOVA test (F=3.4; P<0.05).

Spatial and temporal variation in species richness

Various diversity indices were calculated from the fourth root transformed method for shrimp post-larvae and juvenile abundance. The Shannon-Wiener diversity index H' (log2), Margalef richness index (d) and Pielou's evenness index (J') were calculated concerning different seasons and stations. Shanon diversity index H' (log2) values ranged from (1.952-2574), and the maximum value (2574) was recorded in SSS1. The minimum value (1.952) was recorded during the PMSS2 (Fig. 12). The Margalef (d) species richness index shows the highest value in SSS1 (2.071); it comprised 04 species (Fig. 13). Pielous's evenness index (j) showed the highest value (0.9966) in SSS2, and lowest value (0.936) was noticed in PMSS3 (Fig. 14). The similarity in species composition and abundance in SSS1, SSS2 and SSS3 were in the range of 72.40-85.94% with an average of 79.1%. In PMSS1, PMSS2 and PMSS3, it varied from 66.06-83.59% with an average of 74.8%. In MSS1, MSS2 and MSS3, it ranged from 58.03-93.67% with an average of 75.8%, while in POMS1, POMS2 and POMS3, it ranged from 63.00-93.28% with an average of 78.1% respectively. The dendrogram drawn revealed five separate groups of seasons and stations. In SSS1 and SSS2, they formed a group at 85.9% similarity, which joined PMSS2 at 83.59% similarity. The PMSS3 and PMSS1 were grouped as one cluster at 82.61% similarity. In POMS2 and MSS2, they formed a group at 86.75% similarity. In MSS3 and MSS1, they formed a group at 93.6% similarity, which joined SSS3 at 85.90% similarity. POMS3 and POMS1 were joined as one cluster at 93.2% similarity (Fig. 15). The cluster results are superimposed by nMDS analysis. nMDS ordination showed that the trajectories of temporal variation in species distribution differed among the four seasons and three stations (Fig. 16). The significant differences in shrimp post-larval and juvenile distribution were assessed seasonally in the Alamparai estuary through ANOSIM, with a global R-value of 0.59 and p<0.05 significant differences in seasonality. An R-value close to 1 indicates an excellent separation of the seasons. The R and p values indicated that communities differed season-wise. A pair-wise test showed significant differences in seasonality in

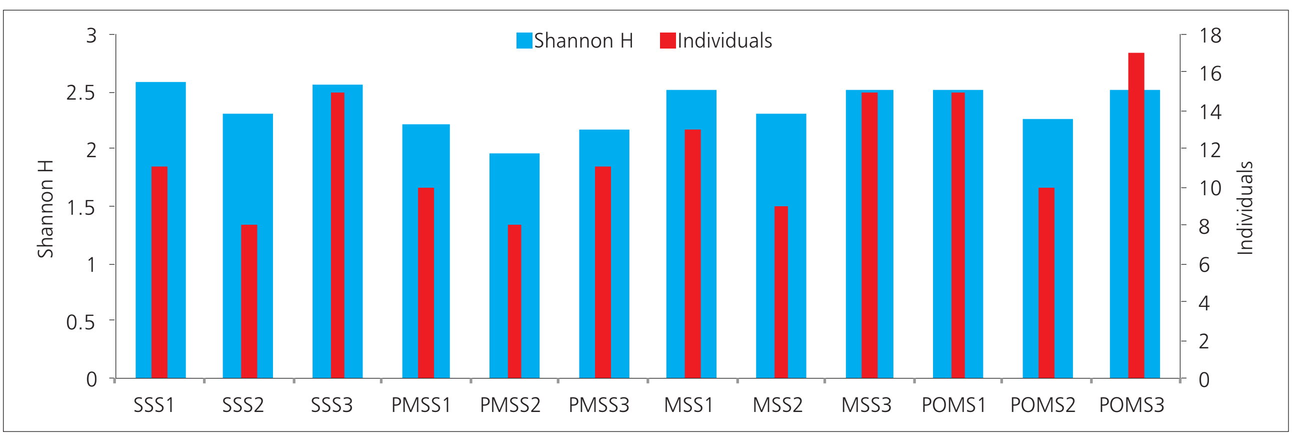

Fig. 12. Shannon-Wiener index and individuals of the Alamparai estuary shrimp post-larvae and juvenile assemblage

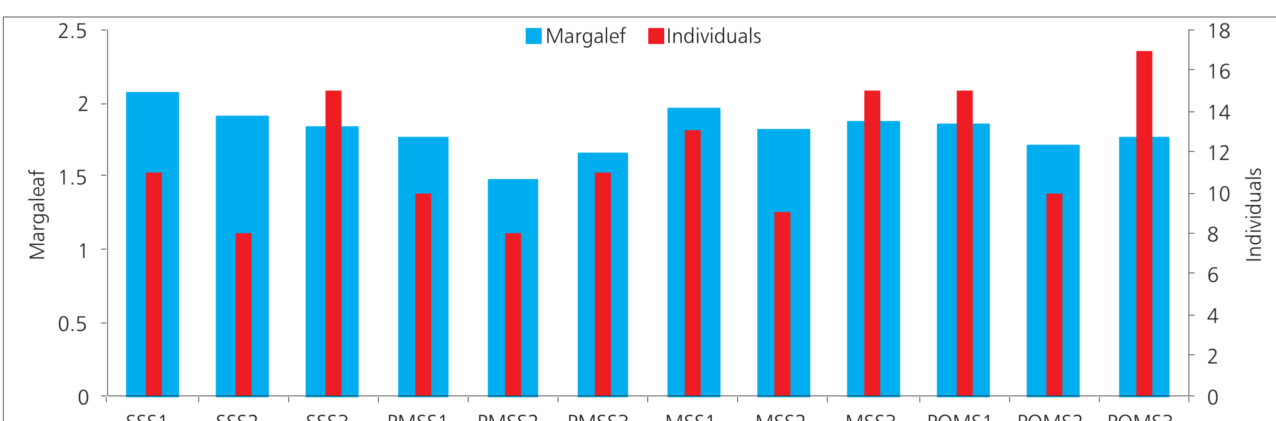

Fig. 13. Margalef species richness index and individuals of the Alamparai estuary shrimp post-larvae and juvenile assemblage

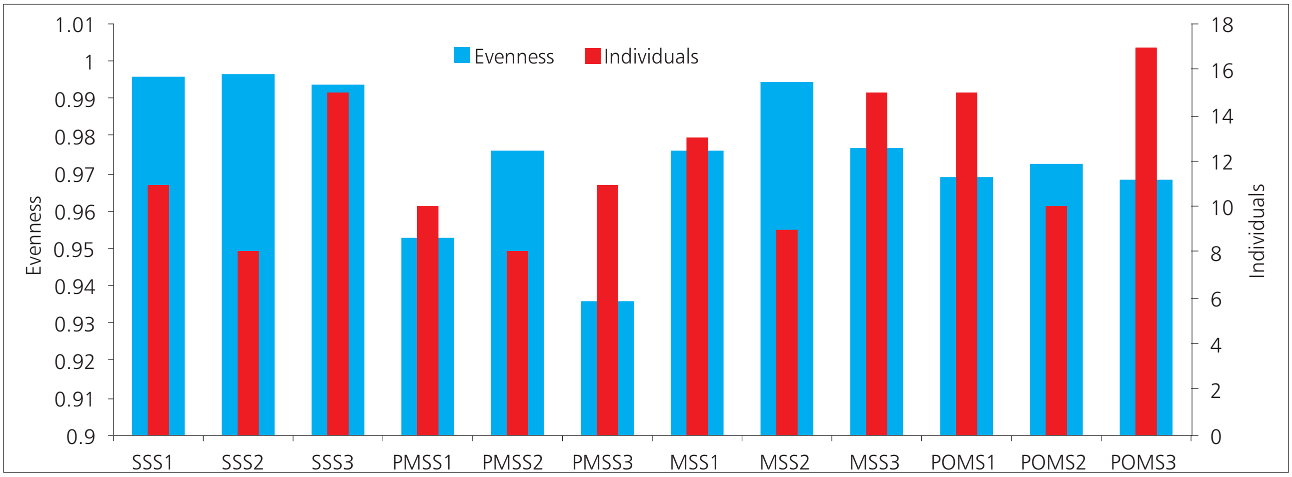

Fig. 14. Pielou's evenness index and individuals of the Alamparai estuary shrimp post-larvae and juvenile assemblage

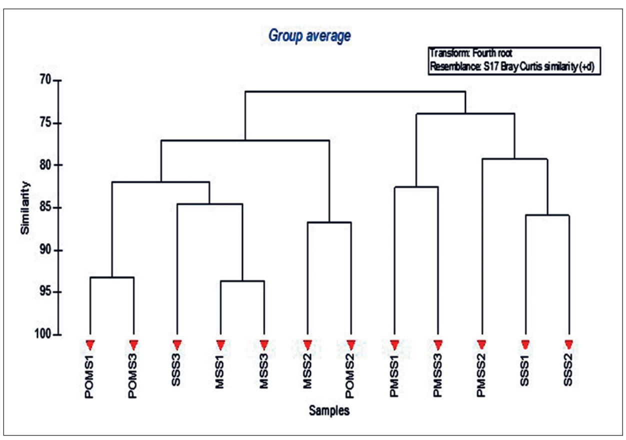

Fig. 15. Spatial and temporal cluster dendrogram of shrimp post-larvae and juvenile assemblage based on Bray-Curtis similarity matrix

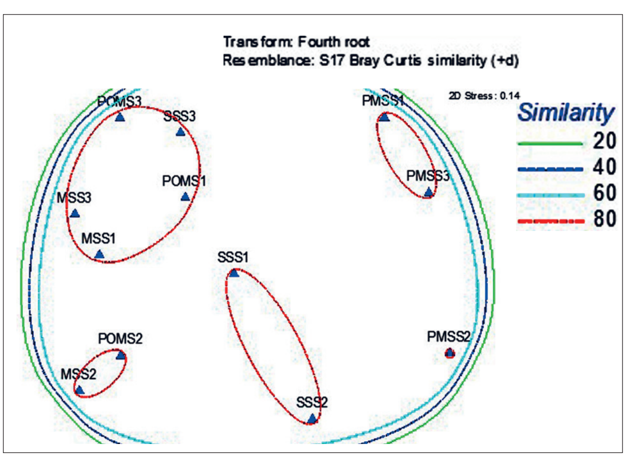

Fig. 16.nMDS showing the spatial and temporal pattern of shrimp post-larvae and juvenile assemblage in Alamparai estuary during the study period

all comparisons, except between the premonsoon and monsoon season (p=1.0) (Table 3). The species were identified as abundant by SIMPER analysis in different seasons in the Alamparai estuary. Monsoon season showed the highest percentage of similarity (83.9%), followed by post-monsoon (83.4%), summer (79.7%) and pre-monsoon (75.9%). (Table 3). The average dissimilarity was between the pre-monsoon & monsoon groups (39.65%), followed by the pre-monsoon and post-monsoon groups (31.78%), summer and pre-monsoon (28.94%), summer and post-monsoon groups (27.18%) summer and monsoon (21.81%) and monsoon and post-monsoon groups (21.69%) (Table 4).

Relationship with environmental variables

The first eigen value 0.402) is fairly high, implying that the first axis represents a fairly strong gradient. The second axis (0.250) is much weaker, and the third axis (0.097) is the weakest. The overall inertia, or variance (in species dispersion) in the data set, is 0.845. The row "cumulative percentage variance of species data" imply that the first axis explains about 47.6% of the total variation (inertia) in the data set. The first two axes explain about 77% of the total variation. The row "cumulative percentage variance of species-environment relation" expresses the amount of inertia explained by axes as a fraction of the total explainable inertia. Thus, the first two axes taken together displayed more than 84% of the variation that the variable could explain. The first two CCA axes define 77% of the cumulative percentage species variance and 84% of the cumulative percentage variance of species-environment relation; therefore, the results for these two axes are plotted (Table 5). The species scores and environmental scores from the ordination are shown in Fig. 17. In general, variables associated with salinity gradient points towards the left and up of the bi-plot, and those associated with dissolved oxygen, nitrite, phosphate and silicate availability point in the right and low of the bi-plot. Accordingly, the species scores highlight that

Table 3. Results of the ANOSIM pairwise test to analyse the differences of the same cluster using groups resulting from the cluster analysis

Groups	R-statistics	Significance level 1%
Summer vs Pre-monsoon	0.556	0.1
Summer vs Monsoon	0.37	0.2
Summer vs Post-monsoon	0.63	0.1
Pre-monsoon vs Monsoon	1.0	0.1
Pre-monsoon v Post-monsoon	0.889	0.1
Monsoon vs Post-monsoon	0.444	0.2

Table 4. Summary results of similarity percentage analysis (SIMPER) on the contribution of shrimp post-larvae and juvenile assemblage in the Alamparai estuary resulting from the cluster analysis.

Groups	Species	% contribution
Summer	*M. monoceros*	20.55
	M. dobsoni	20.36
	P. semisulcatus	20.09
	P. indicus	18.73
	P. monodon	15.53
Pre-monsoon	*P. indicus*	39.74
	M. monoceros	28.09
	M. dobsoni	21.71
	M. brevicornis	5.86
Monsoon	*P. monodon*	22.34
	M. brevicornis	20.95
	P. semisulcatus	20.51
	M. dobsoni	16.51
	P. indicus	15.59
Post-monsoon	*P. indicus*	27.94
	M. brevicornis	24.09
	P. monodon	16.51
	M. dobsoni	14.5
	P. semisulcatus	12.81

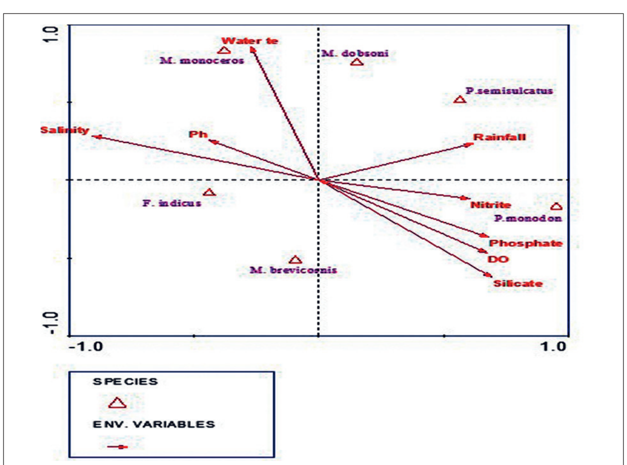

Fig. 17. The CCA ordination of shrimp post-larvae and juvenile abundance and environmental variables

the shrimp post-larvae and juvenile distribution is influenced mainly by a salinity gradient and dissolved oxygen availability (first axes explain the 47%; F-ratio=3.741; p=0.010). Overall, the shrimp post-larvae and juveniles were associated with higher salinity values. Moreover, water temperature, rainfall and pH are other important factors influencing the species distribution, which may be due to seasonal variations. Among the physicochemical parameters, four showed a significant correlation with juvenile shrimp communities (Table 6). For example, *P. monodon* showed a significant positive correlation with dissolved oxygen, Silicate while negatively correlated with salinity. Similarly, *M. dobsoni* and *M. monoceros* showed a positive correlation with water temperature.

Discussion

In the present study seasonal variation and density of *P. monodon* and *M. brevicornis* were observed in similar patterns. The peak abundance of post-larvae of *P. monodon* and *M. brevicornis* was observed in the monsoon and post-monsoon seasons. A minor peak was noticed in the summer season. This may be due to heavy rainfall during the monsoon season, depleting the salinity of the estuarine waters, which increases during the post-monsoon seasons. Since the primary productivity seems to be more during this period, it is quite natural except for higher recruitment and settlement of post-larvae and juveniles of penaeid shrimps. Hoq *et al.* (2001) recorded the

Table 5. Results of canonical correspondence analysis performed on shrimp post-larvae and juvenile abundance, relation to environmental variables in the Alamparai estuary

Axes	1	2	3	4
Eigen values	0402	0.250	0.097	0.014
Species-environment correlations	0.954	0.982	0.912	0.940
Cumulative percentage variance of species data	47.6	77.2	88.7	90.3
of species-environment relation	52.4	84.9	97.6	99.4
Sum of all eigen values (total inertia)				0.845
Sum of all canonical eigen values				0.768
Summary of Monte Carlo test				
Test of significance of all canonical axis				
Trace	0.768*			
F-ratio	3.741*			
P-value	0.010*			
Rainfall	0.58	0.23	-0.60	0.07
Water Temperature	-0.25*	0.84	-0.009	-0.20
Ph	-0.41*	0.25	0.71	-0.29
Salinity	-0.86*	0.28	0.23	-0.13
Dissolved oxygen	0.64*	-0.45	-0.41	0.21
Nitrite	0.64	-0.35*	-044	0.35
Phosphate	0.57	-0.11*	-0.62	0.32
Silicate	0.65	-0.61*	-0.24	0.22

*Inter-set > |0.4| corresponding to biologically important variables.

maximum abundance of *P. monodon* post-larvae in Sundarban mangroves between October-February. A similar observation of post-larvae and juveniles was also noticed in Muthupet mangroves (Mohan *et al.,* 1995). Manja Naik *et al.* (2009) encountered a maximum abundance of *P. monodon* seeds in the Mulki estuary in January and February. This may be due to the lower salinity and temperature resulting in the meagre availability of *P. monodon* (De and Sinha, 1997).

During the study period, *P. indicus* post-larvae, and juveniles were noticed throughout the year. The quantum of post-larvae and juveniles was recorded in two peaks, the first peak post-monsoon and the second peak in premonsoon season. The same pattern of abundance has been reported by Mohan *et al.* (1995) in Muthupet mangroves; Easo and Mathew (1989) in Cochin backwaters; Rajendran and Kathiresan (1999) from Pichavaram mangroves, Southeast coast of India. Manja Naik *et al.* (2009) in Mulki estuary; Hoq *et al.* (2006) in Sundarban mangroves. In addition, Selvaraj *et al.* (2005) reported that *P. indicus* seeds were relatively more during the premonsoon season in Cochin backwaters. Silambarasan *et al.* (2012) also reported similar observations that *P. indicus* seed was predominant in the samples collected in premonsoon months in the Palar estuary. The present study revealed moderate rainfall and preferred salinity patterns for successful settlement and growth of penaeid shrimps.

The density of *M. dobsoni* post-larvae and juveniles was recorded throughout the year. The maximum abundance was recorded in the summer season. Kuttiyamma (1980) recorded a maximum abundance of *M. dobsoni* seed in Cochin backwaters between September and January, whereas, Kuttiyamma and Kurian (1982) observed the post-larvae of *M. dobsoni* throughout the year, with a peak in post-monsoon along Cape Comorin, Quilon and Cochin coasts. Similarly, Manja Naik *et al.* (2009) encountered the same species throughout the year with peak abundance during December, January and February. This may be due to relatively high temperature, pH and salinity, which may stimulate spawning activity during those seasons.

In the present study, we observed that *P. semisulcatus* post-larvae and juveniles were abundant in monsoon and summer seasons. Moreover, station III (mangrove area) had the maximum abundance of post-larvae and juveniles in the seagrass and algal beds. Sambandam (1994) observed that good numbers of *P. semisulcatus* collected from the algal flora and submerged mangrove vegetation due to its green colour and association with aquatic weeds. In addition, Bishop and Kahn (1991) also recorded *P. semisulcatus* post-larvae abundance closely tied to the distribution of submerged vegetation in Kuwait Bay. Similar observations were made by Rao and Gopalakrishnayya (1974) and Tom *et al.* (1984). The present study confirms the earlier findings, particularly in station III, which, is situated in mangroves, seagrass zone and algal beds, a possible reason for the abundance of *P. semisulcatus* post-larvae and juveniles.

The maximum abundance of *M. monoceros* post-larvae and juveniles was recorded in the premonsoon season, which agrees with the findings of Kuttiyamma (1980) in Kayamkulam backwaters; Kuranty (1983) in Ngomeni lagoon; Easo and Mathew (1989) from Cochin backwaters. The abundance of

Table 6. Pearson correlation of environmental parameters with relation to shrimp post-larvae and juvenile communities in Alamparai estuary during the study period.

	Rainfall	WT	pH	Sal	Do	N	P	S	*P. indicus*	*P. monodon*	*P. semisulcatus*	*M. dobsoni*	*M .monoceros*	*M. brevicornis*
Rainfall	1													
WT	-0.126	1												
pH	-.743**	0.511	1											
Sl	-.691*	.616*	.721**	1										
DO	.699*	-.667*	-.884**	-.899**	1									
N	.705*	-.639*	-.894**	-.903**	.971**	1								
P	.835**	-0.483	-.947**	-.836**	.925**	.959**	1							
S	0.576	-.790**	-.795**	-.931**	.952**	.946**	.847**	1						
P. indicus	-0.395	0.003	0.074	0.296	-0.12	-0.168	-0.223	-0.085	1					
P. monodon	0.51	-0.356	-0.46	-.753**	.621*	0.571	0.542	.657*	-0.092	1				
P. semisulcatus	0.166	0.202	0.065	-0.359	0.113	0.147	0.095	0.167	-0.333	.583*	1			
M. dobsoni	-0.217	.602*	0.486	0.184	-0.38	-0.388	-0.422	-0.353	0.012	0.077	.731**	1		
M. monoceros	0.101	.782**	0.115	0.443	-0.361	-0.338	-0.148	-0.485	0.273	-0.306	-0.042	0.327	1	
M. brevicornis	-0.436	-0.361	0.117	0.003	0.065	-0.017	-0.209	0.198	.757**	0.215	-0.039	0.061	-0.28	1

WT-Water temperature, Sl-Salinity, DO-Dissolved oxygen, N-Nitrite, P-Phosphate, S-Silicate

*Significant level at 0.05 ($p < 0.05$). ** Significant level at 0.01 ($p < 0.01$).

the post-larvae and juveniles was in the higher temperature and lower salinity inputs. This could be attributed to the peak breeding period of its adults and their larval recruitment period in the Alamparai estuary.

Ecological indices like Shannon-Wiener diversity, Margalef richness, and Pielou's evenness are useful in the community structure of species assemblages (Xu *et al.,* 2012). The species diversity (H) values were recorded as maximum (2.574) in summer, and minimum values were recorded in premonsoon (1.952). A similar trend has been obtained by Pushparajan *et al.* (2012) in Pichavaram mangroves. The maximum species richness values (2.071) were observed in the summer season, and the minimum species richness values were observed in pre-monsoon (1.475). The values in the present study were higher than (0.78 to 0.81) those reported by Pushparajan *et al.* (2012) from Pichavaram mangroves.

The maximum evenness values were recorded in the summer (0.9966) and the minimum value (0.936) in pre-monsoon. Similar species evenness values were recorded by Srilatha *et al.* (2013) (0.86-0.96) for finfish eggs and larvae abundance from Point-Calimere and Muthupetai mangroves and also Pushparajan *et al.* (2012) (0.80-0.89) for shrimp seed from Pichavaram mangroves.

It is widely acknowledged that many interacting physical, chemical and biological factors influence the occurrence, distribution, abundance and diversity of penaeid shrimps. Among the environmental variables like water temperature, salinity, dissolved oxygen and nutrients are the most important abiotic factors influencing the growth and survival of penaeid post-larvae and determining the fishery (Rao and Gopalakrishnayya, 1974; Easo and Mathew, 1989).

The influence of rainfall on shrimp fisheries has been studied by several authors *viz.,* Barrett and Gillespie (1973, 1975); Staples (1980a); Staples and Vance (1987) and others. Subrahmonyam (1967) studied the influence of river discharges on prawn fisheries of the Godavari estuarine system. Water temperature showed seasonal variation and had the greatest influence on the shrimp post-larvae and juvenile assemblage of the estuary, probably due to the water temperatures coinciding with the breeding season for most penaeid shrimps. Seasonal fluctuations in shrimp post-larvae and juvenile density, and diversity were recorded in the Alamparai estuary, with the highest mean density, and diversity occurring in the post-monsoon season due to optimum temperature and lower salinity conditions and this might be due to the preference for penaeid shrimps to spawn in favourable conditions of salinity and temperature. This investigation agrees well with the observations made by Staples, (1983) from South Eastern Gulf of Carpentaria and Easo and Mathew (1989) from the Cochin backwaters.

Salinity is an important determinant of the shrimp population, inducing the emigration of adult shrimps and influencing post-larval recruitment (Garcia and Le Reste, 1981). Staples and Vance (1987) reported that season and rainfall directly affected the immigration of post-larvae and emigration of juveniles. Mohan *et al.* (1995) suggested moderate rain extending the nursery area with preferred salinity regimes for successful settlement and growth of penaeid shrimps from Muthupet mangroves. Rajendran and Kathiresan (1999) reported that rainfall and salinity significantly correlated with shrimp post-larvae from Pichavaram mangroves.

Several authors suggested that temperature and rainfall may affect *P. semisulcatus* catches, but the results still need to be confirmed statistically. Vedavyasa Rao and Kathirvel (1971) reported a decrease in catches of *P. semisulcatus* in Cochin backwaters during seasonally low salinities. Rao and Gopalakrishnayya (1974) suggested that high temperature and salinities (and therefore low rainfall) were associated with good growth and survival of *P. semisulcatus.* Su and Liao (1987) found an association between low salinities and the emigration of adolescents of *P. semisulcatus* from nursery areas using set nets in Taiwan. There was no consistent relationship between rainfall or salinity and size but catches increased after heavy typhoon rainfall.

The proportion of variation in post-larval and juvenile catches that was explained by environmental variables in our study was very low. These results suggest that *P. semisulcatus* lives in such widely different environments, except in extremes such as cyclone-induced rainfall, environmental variation has little effect on juvenile abundances. It is, therefore, unlikely that predictive models of adult *P. semisulcatus* catches can be developed based on environmental factors acting on the estuarine stages of the life cycle.

Dissolved oxygen concentration is another major factor triggering the species distribution. Dissolved oxygen generally affects the survival of fishes and shrimps, especially juveniles and fry. Chowdhury *et al.* (2010) mentioned that dissolved oxygen is one of the most important factors for fish and prawn abundance and distribution. Easo and Mathew (1989) noticed that the minimum level of dissolved oxygen content has a non-significant role in the distribution and abundance of prawn seed in the natural ecosystem and that high dissolved oxygen is optimum for the seed. The present study confirmed that maximum shrimp post-larvae and juvenile density coincided with the high dissolved oxygen content of the waters. The observed dissolved oxygen content in the present study ranged between 3.2 to 7.07 mg l^{-1}.

pH (Hydrogen ion concentration) is a prime factor in the chemical and biological systems of natural waters, It is used to determine the degree of acidity, and it has a direct relationship with respiration and photosynthesis (Naik and Purohit, 1997). Easo and Mathew (1989) noticed that pH values of 7.3-8.2 had little effect on the seed abundance, but values less than 7.0 had adverse effects. The observed pH values ranged from 6.2 to 8.1. The present study confirms that the optimal pH influences the abundance of shrimp post-larvae and juveniles. In the present study, higher pH values were recorded during the summer season and lower in the monsoon season. The high pH might be due to the uptake of CO_2 by photosynthesizing organisms especially phytoplankton, zooplankton and meroplankton from the seawater would have increased the pH levels during the summer season.

The distribution and behaviour of nutrients in the coastal environments, particularly near-shore waters and estuaries, would exhibit considerable seasonal variations, and it depends on freshwater input, rainfall and land drainage. In the present study, high values of nitrite were observed during the monsoon season and low values during the summer season. Moreover, the abundance of shrimp post-larvae and juveniles was negatively correlated to nitrogen. The high phosphate values were recorded in the monsoon season due to rainfall and river discharge resulting in massive transportation of sediment and a rise in phosphate concentration during the monsoon period. More density of shrimp post-larvae and juveniles increased phosphate utilization which might have resulted in the decrease of nutrients during the pre-monsoon and late post-monsoon months. Silicate concentration showed marked seasonal patterns; high silicate concentrations were accompanied by post-monsoon season and monsoonal drainage associated with the heavy silt load in the estuarine water. Similar observations were made by Easo and Mathew (1989) from the Cochin backwaters. The present study suggested shrimp larvae and juveniles are mainly detrivores. The availability of detritus depends on the primary and secondary productivity of the estuary, which in turn depends on the nutrient availability, in the water. Thus the nutrient concentration in water could have indirectly influenced the abundance of shrimp larvae and juveniles.

A single factor is not responsible for the recruitment, dispersal and abundance of shrimp post-larvae and juveniles. According to Zein-Eldin and Aldrich (1965), passive and active transport were also responsible for the overall recruitment and abundance of shrimp post-larvae and juveniles in the study area. In the present study also, the combination of factors like rainfall, water temperature, salinity, dissolved oxygen, pH and other factors like food sources, shelter, currents and sediments were responsible for the distribution and abundance of shrimp post-larvae and juveniles. In addition, apart from any nutrient quality, it must be the natural breeding season of the species that matters most in the distribution and abundance of larvae. It is a fact that many of these physicochemical parameters act as a cue for breeding.

Conclusion

Since shrimp culture technology is well developed in India, the need for natural seed resources and stock potential is now greater. The Alamparai estuarine environment offers a vast potential for developing shrimp farms. The present study concluded the availability of shrimp post-larvae and juveniles in the Alamparai estuary throughout the year. However, natural seed collection is also important for small-scale fisheries, and the scientific documentation on the availability and assemblage structure of the post-larvae and juvenile shrimps is important to ascertain the health of the stock and fishery. Moreover, the information provided in this study would certainly be an additional source to the intervention of shrimp resources and constitute potentialities for shrimp culture.

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