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Hydrologic and sediment parameters affecting the distribution of the Venerid clam, Paphia malabarica in two estuaries

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Abstract- An estuary is a unique area exhibiting environmental and biological gradients. The estuarine species prefer an optimum niche along this gradient. The environmental parameters have relative influence on species diversity, biomass and population density of macrobenthos. We analysed the density and distribution of the edible clam, *Paphia malabarica* in the two tropical estuaries (Ashtamudi estuary, a deep lake and Kayamkulam estuary, a shallow lake in the south-west coast of India) in relation to the varying environmental factors for two years. The observations clearly indicated the existence of significant relationship between the biological and environmental variables. The density and distribution of the clam illustrated spatio-temporal variations in relation to the changing hydrologic and sediment parameters. Peak clam density values were obtained in the premonsoon followed by postmonsoon and least in the monsoon. The lower reaches were denser than the upper reaches of the estuary. The results of the study revealed that the density and distribution of the clam *Paphia malabarica* in the two estuaries were predominantly influenced by the environmental parameters such as salinity, organic carbon, sediment p^H and sand fraction of sediment. The density and distribution of the clam was found decreasing in a decreasing gradient of these factors.

Index Terms- density, distribution, estuary, environmental gradients, *Paphia malabarica*.

I. Introduction

The distribution of species in nature in relation to the varying environmental factors still leaves a critical issue in ecological research. The benthic ecologists conceive the ecological process by examining the interrelationship between environmental parameters and benthic community structures. The environmental parameters have relative influence on species diversity, biomass and population density of soft bottom macro-fauna. The increased discharge of the river at first reduces salinity of the surface layers and then as turbulence increases, the substrate of the estuary is affected and in extreme cases the whole estuary may become fresh. This type of episodic event has a major direct effect on the benthic fauna. In general, there are many factors that play an important role in regulating the distribution and abundance of the bivalves in the ecosystem. Competition, inter as well as intra species, can also play a major role in limiting faunal abundance and distribution. These factors, when combined with the effects of various physicochemical factors such as salinity, temperature, dissolved oxygen, grain size of sediment and distribution along the depth gradient in the estuarine environments, result in very complex spatial and temporal patterns in the structure of the faunal assemblages.

Estuarine species occur along environmental and biological gradients with each species having an optimum niche along a gradient. Studies of Macfarlane and Booth (2001); Morrisey *et al.(*2003); Currier and Small(2005); Nouri *et al*.(2008)and Aweng *et al.* (2012) have shown that the distributional patterns of macrobenthos are closely linked to environmental factors. The variations in abundance and distribution patterns of the bivalves within estuarine systems have been correlated with environmental variables such as salinity(McLusky, 1986; Holland *et al.*,1987; Maes *et al.*, 1998 and Cervetto *et al.*, 1999), tidal level (Warwick and Uncles,1980), biotic interactions (Wilson,1991), perturbation (Diaz and Rosenberg,1995) or sediment characteristics (Chapman and Tolhust, 2004). Knowledge of the spatial distribution patterns of macrobenthos along estuarine gradients might help to identify the linkages between species distributions and ecological processes and therefore to gain insight into the functioning of estuarine ecosystems (Thrush *et al.*, 1999), which is essential for implementation of integrated estuarine management. Knowledge of the habitat or site dependence of ecological processes is critical in estuaries, which are known to exhibit substantial spatial and temporal variability in physical properties and some biological properties. These variations affect the habitat preferences of benthic organisms and thus in their density and distribution. From the point of view of sustainable fishery and conservation of the stock, it is necessary to record the density and distribution of bivalves in the estuary. In this paper we have made an attempt to analyse the impacts of varying environmental factors on the density and distribution of the edible bivalve species, *Paphia malabarica* in two Lake Systems.

II. MATERIALS AND METHODS

A. Study area

Ashtamudi Lake, a Ramsar site, located between latitude 8^0 53'-$9^0$2' N and longitude $76^0$31' – $76^0$41'E. It has a water spread area of about 32 km^2. The main basin is about 13 km long and the width varies from a few 100 meters to about 3 km and the average depth is1.5m with the maximum depth of 6.4 m at the confluence zone. The Kayamkulam Lake is located between latitude $9^0$2'-$9^0$16' and longitude $76^0$25'-$76^0$32'E. It is a narrow stretch of linear water body having a length of about 24 km. Its width varies from a few tens of meters to over a kilometer and depth of 0.5m to 2.5meter .The two estuaries remains connected to the Arabian Sea throughout the year.

B. Sampling

Six sampling sites were fixed in the clam beds of both the estuaries.

C. Clam sampling

Quadrat sediment samples were collected from the sampling sites of both the estuarine systems at monthly intervals. At each sampling site four quadrat (0.25m^2) were marked on the clam beds. The bivalves were collected after the sediment had been washed through a 5mm mesh net and mean clam density was calculated.

D. Water sampling

Monthly bottom water samples were collected from the marked sites by Niskin water sampler. The sampling was done for two years. Measurements of temperature, p^H and fixation of dissolved oxygen were done in the field at the time of sample collection. Water for the analysis of all other parameters was collected in acid cleaned and pre-rinsed glass bottles and was taken to the laboratory under refrigeration. Salinity was determined by Mohr-Knudsen argentometric titration method (Strickland and Parsons,1968) and was measured using the Practical Salinity Scale. Dissolved Oxygen fixed in situ was analysed in the lab following modified Winkler's method (Strickland and Parsons, 1968). p^H was measured immediately after collection using a portable p^H meter. Temperature of the water was recorded using a mercury filled Celsius thermometer.

E. Sediment sampling

The sediment samples were collected from each sampling point to a depth of 20cm. Bivalves were separated from sediment samples using 5mm mesh net. The soil samples were air dried and were used for the analyses of soil parameters such as sediment texture (%) by pipette analysis (Krumbein and Pettijohn, 1983), sediment p^H, electrical conductivity (mS/cm) using RD 26 Solu-Bridge, organic carbon (%) by Walkley- Black method (1934), phosphorus (mg/g) by sodium bicarbonate method (Olsen *et al.*, 1954) and potassium (mg/g) by Flame photometric method (APHA, 1998).

F. Data analyses

The data were pooled seasonally and the results were subjected to suitable statistical analysis using Statistical Package for the Social Sciences (SPSS 20.0 version).The differences in the observed environmental parameters and biological parameters were tested using ANOVA. When a significant difference was detected using ANOVA, a post-hoc test was done using *Duncan's Multiple Range Test* (*DMRT*).Correlation analysis was conducted to determine correlation between the environmental parameters and the biological parameters. Independent student's *t-test* was carried out to determine the difference in means between the two estuaries. Principal Component Analysis (PCA) was carried out to determine the significant environmental variables influencing the density and distribution of clams in the estuaries.

III. RESULT

A. Density and distribution of the clam

The spatio-temporal variations in the density of *Paphia malabarica* in the Ashtamudi estuary and Kayamkulam estuary are given in Figure 1. *Paphia malabarica* was densely populated in the estuarine zone of Ashtamudi estuary. It showed a gradation in distribution from the sites near the estuarine mouth to the upper reaches in a decreasing salinity gradient. During the premonsoon the clam density varied between 45.38 ± 10.09 number / m^2 in site VI and 928.3 ± 76.58 number / m^2 in site I with an average of 294.88 ± 42.92. In the monsoon the clam density variegated from49.75± 13.85 number / m^2 in site VI and 459.5 ± 296.7 number / m^2 in site I with an average of 189.33 ± 78.61. In the postmonsoon the clam density ranged from41.13±9.95 number / m^2 in site VI and 847.1±119.7 number / m^2 in site I with an average of 262.52 ± 45.92. The analysis of variance showed that the differences in densities of clam was significant both between seasons (P< 0.000) and sites (P <0.000). Duncan's Multiple Range Test (*DMRT*) was applied and it showed that the differences were significant at all sites in all the three seasons. In the Kayamkulam estuary, in the premonsoon the density variegated from 69 ±31.18 number / m^2 to 154.9 ± 42.93 number / m^2 with an average of 105.01± 28.5. In the monsoon the density varied from 25.25± 17.13 number / m^2 to 74.63± 34.02 number / m^2 with an average of 42.77 27.09. In the postmonsoon the mean density fluctuated from to 69.13 ± 23.78 number / m^2 to 161± 30.14 number / m^2 with an average of 93.21 ± 29.32. The analysis of variance showed that the difference between the mean values were significant between seasons (P<0.000) and between the sites (P< 0.000). The *DMRT* showed that the mean value of postmonsoon was more significant than the other seasons.

The clam *Paphia malabarica* was obtained from all the sites observed in both the Lakes in all seasons. The site I was denser than the others in Ashtamudi estuary where as the site I was less dense than other sites in Kayamkulam estuary. In the pre-monsoon the mean density of *Paphia malabarica* was recorded as 294.9 ± 42. 59 in Ashtamudi estuary and 105.01 ± 28.5 in Kayamkulam estuary. In the monsoon the density of *Paphia malabarica* in Ashtamudi estuary was noted as 189.33 ± 78.61 and in Kayamkulam estuary as 42.77 ± 27.09. In the postmonsoon the density of *Paphia malabarica* in Ashtamudi estuary was found to be 262.52 ±45.92 and in Kayamkulam estuary as 93.21 ± 29.32. The mean density of clam *Paphia malabarica* during the study period in Ashtamudi estuary was recorded as 248.92 ± 55.71 and in Kayamkulam estuary as 80.33 ± 28.3. The variations in mean values of density between the two estuarine systems were significant at 5% level (t=8.368, P<0.000) (Table III).

The correlation studies on the data of Ashtamudi estuary revealed that the density of *Paphia malabarica* was positively correlated with salinity, sediment electrical conductivity, phosphorus and negatively correlated with dissolved oxygen (Table I).In the Kayamkulam estuary it was observed that the clam density was positively correlated with salinity, sediment p^H, potassium and have negative correlation with dissolved oxygen and phosphorus (Table II).

B. Hydrologic parameters

The mean salinity values in the Ashtamudi estuary showed a spatio-temporal variation in the estuary (Figure 2). A salinity gradient was evident in the estuary, with mean salinity increasing from the upper reaches (site VI) to site near barmouth (site I) of the estuary. The mean salinity values of the sites varied from 23.49 ± 2.77 to 26.78 ±4.48 with an average of 25.28 ± 3.68 in the premonsoon. In the monsoon the salinity values fluctuated from 20.46 ± 7.29to 23.08 ± 7.7 with an average of 21.81 ± 7.42. In the post monsoon the mean salinity values ranged from 19.81± 5.3 to 24.02 ±4.99 with an average of 22.02 ± 5.11 .The statistical analysis showed significant variation in mean salinity values between season ($P < 0.004$). No significant variation in salinity was observed between the sites studied. Duncan's multiple range test (*DMRT*) of salinity showed that the mean value of salinity in the premonsoon was significantly different from other seasons. The salinity showed highly significant negative correlation with dissolved oxygen, p^H of water and phosphorus and significant positive correlation with sediment pH, electrical conductivity and potassium (Table I). The mean salinity values of Kayamkulam estuary during the premonsoon period fluctuated from 23.73 ± 8.98 to 26.61±5.4 with an average of 25.32 ± 6.88 (Figure 3). In the monsoon the mean salinity values varied from 17.17 ± 7.66 to 23.47± 3.44 with an average of 20.41 ± 5.39. In the postmonsoon the mean salinity values departed from 23.22 ± 5.97 to 25.76 ± 3.9 with an average of 24.55 ± 4.83. The statistical analysis showed significant variation in mean salinity values between seasons ($P < 0.000$). Duncan's multiple range test of salinity showed that the mean value of salinity in the monsoon was significantly different. The salinity showed highly significant negative correlation with dissolved oxygen (Table II).

The average dissolved oxygen values showed spatio-temporal variations (Figure 2). There was an increase in the mean values of dissolved oxygen from the sites near the estuary mouth to the sites in the upper reaches. The mean dissolved oxygen values varied from 3.33±0.96 mgl^{-1} and 4.90±0.64 mgl^{-1} with an average of 4.04 ± 0.79 in the premonsoon. In the monsoon the dissolved oxygen values fluctuated from 4.91±1.49 mgl^{-1} to 5.54±2.71 mgl^{-1} with an average of 5.17 ± 1.98. In the post-monsoon the dissolved oxygen values changed from 3.33 ± 0.99 mgl^{-1} to 5.30 ± 2.65 mgl^{-1} with an average of 4.22 ± 1.78. The Analysis of Variance (ANOVA) of dissolved oxygen in different sites in the Ashtamudi estuary showed that the variations were significant both between the season ($P<0.003$) and sites ($P<0.004$). *DMRT* showed that the mean value of monsoon was significant from that of the other two seasons. The dissolved oxygen showed significant positive correlation with p^H and negative correlation with temperature, sediment pH, electrical conductivity (Table 1). The mean values of the dissolved oxygen in the Kayamkulam estuary during the study period are depicted in figure 3. The dissolved oxygen values fluctuated from 3.93 ± 0.742 mgl^{-1} to 4.85 ± 1.14 mgl^{-1} with an average of 4.38 ± 0.93 in the premonsoon. In the monsoon the dissolved oxygen values varied from 4.78 ± 1.58 mgl^{-1} to 5.21 ± 2.23mgl^{-1} with an average of 4.99 ± 1.94. In the post-monsoon the dissolved oxygen values variegated from 4.60 ± 1.4 mgl^{-1} to 5.13 ± 1.84 mgl^{-1} with an average of 4.85 ± 1.65. The ANOVA of dissolved oxygen in different sites in the Kayamkulam estuary showed that the variations were not significant both between the season and sites. The dissolved oxygen showed highly significant negative correlations with temperature, sediment p^H, electrical conductivity and sediment potassium and positive correlation with sediment phosphorus (Table II).

The mean values of water pH in the premonsoon departed from 7.88 ± 0.32 to 8.07 ± 0.229 with an average of 7.98 ± 0.263. In the monsoon the p^H values altered from 8 ± 0.2 to 8.14 ± 0.179 with an average value of 8.09 ± 0.189. In the postmonsoon the mean values of pH variegated from 7.99 ± 0.243 to 8.03± 0.278 with an average of 8.01± 0.263. The pH values of the estuarine water remained alkaline throughout the study period (Figure 2). The variations in pH values were statistically not significant both between sites and seasons. The p^H showed significant negative correlation with temperature and sediment pH and highly significant positive correlation with the sediment phosphorus (Table I). The average p^H values of water in the Kayamkulam estuary during the premonsoon varied from 7.97 ± 0.3 to 8.02 ± 0.32 with an average of 7.99 ± 0.31 (Figure 3). In the monsoon the pH values altered from 7.91 ± 0.385 to 7.95 ± 0.34 with an average value of 7.93 ± 0.36. In the postmonsoon the mean values of pH changed from 7.86 ± 0.409 to 7.91± 0.234 with an average of 7.88 ± 0.32. The variations in values of p^H were statistically not significant both between sites and seasons. The study area of the Kayamkulam estuary exhibited an alkaline inclination throughout the entire study period. The water p^H showed highly significant positive correlation with sediment phosphorus, potassium, organic carbon and sediment (TableII).

The spatio-temporal variations in the average values of water temperature at Ashtamudi estuary showed that in the premonsoon the mean values deviated from 28.56 ± 1.45 °C to 28.63 ± 1.33° C with an average of 28.60 ± 1.386 (Figure 2). In the monsoon the mean temperature values fluctuated from 27.21 ± 0.786 °C to 27.44 ± 0.678°C with an average of 27.34 ± 0.98. The mean values of temperature in different sites in the postmonsoon varied from 27.51 ± 0.871°C to 28 ± 1.035°C with an average of 27.78 ± 0.94. ANOVA of temperature during the study period showed that the variations in mean values between the season was significant ($P<0.000$). *DMRT* showed that the variation in mean temperature values of premonsoon was significantly different from that of the other seasons. The mean values of water temperature at the Kayamkulam estuary in the premonsoon variegated from 28.81 ±1.85 °C to 28.88 ± 1.66° C with an average of 28.84 ±1.76 (Figure 3). In the monsoon the mean temperature values deviated from 27.19± 1.067 °C to 27.38 ± 0.876°C with an average of 27.28 ± 0.97. The mean values of temperature in different sites in the postmonsoon departed from 27.50 ± 1.58°C to 27.81 ± 1.16°C with an average of 27.66 ± 1.37. ANOVA of temperature during the study period showed that the variations in mean values between the season was significant ($P<0.000$) whereas the variation between the sites were not significant. DMRT showed that the variation in mean temperature values of premonsoon was significantly different

C. Hydrologic parameters-Difference between estuarine systems.

The differences in the mean values of the hydrologic parameters studied in the Ashtamudi estuary and Kayamkulam estuary is depicted in Table III.

The mean salinity value of Ashtamudi estuary was recorded as 23.04 ± 5.727 and that of Kayamkulam estuary as 23.43 ±

6.347. The variations between the locations were not significant at 5% level ($t_{(286)} = {}^{-}0.548$, P=0.584). The mean dissolved oxygen values recorded in the Ashtamudi estuary and Kayamkulam estuary were 4.48 ±1.792 mgl^{-1} and 4.74± 1.543mgl^{-1} respectively. The variations in mean values of dissolved oxygen between the locations were not significant at 5% level ($t_{(286)} = {}^{-}1.328$, P=0.185). The mean p^H values recorded for Ashtamudi estuary and Kayamkulam estuary were 8.02 ± 0.239 and 7.94 ± 0.32 respectively. It was observed that the mean value of p^H in Ashtamudi estuary had statistical significance when compared to the mean value of Kayamkulam estuary ($t_{(286)}$ =2.649, P=0.009). The mean values of temperature recorded from the Ashtamudi estuary and Kayamkulam estuary were 27.89 ± 1.195° C and 27.93 ± 1.488° C respectively. The variations in mean values of temperature between the locations were not significant at 5% level ($t_{(286)} = {}^{-}0.227$, P=0.820).

D. Sediment parameters

The mean sediment p^H values showed that the sediment of clam bed at Ashtamudi estuary was acidic throughout the study period (Figure 4). In the premonsoon the p^H values ranged from 6.93 ± 0.86 to 6.97± 0.94 with a mean value of 6.95± 0.89. In the monsoon the p^H values deviated from 6.30 ± 1.37 to 6.49 ± 1.4 with an average of 6.41 ±1.42. In the postmonsoon the sediment p^H values varied from 5.52 ± 0.966 to 5.93 ± 1.43 with an average value of 5.676 ±1.15. The analysis of variance showed significant differences between mean values of season (P<0.001). The Duncan's multiple range test of sediment p^H showed that the mean values of sediment p^H were significantly different in the three seasons. The sediment pH showed significant negative correlations with organic carbon and phosphorus (Table 1). The mean sediment p^H values of clam bed at Kayamkulam estuary are detailed in figure 4. In the premonsoon the p^H values varied from 6.93± 0.97 to 7.13± 0.94 with a mean value of 7.02± 0.95. In the monsoon the p^H values departed from 6.21 ± 1.6 to 6.35± 1.6 with an average of 6.29 ±1.6. In the postmonsoon the sediment p^H values altered from 6.33 ± 1.19 to 6.40 ± 1.19 with an average value of 6.36 ±1.2. The statistical analysis of variance showed significant difference in p^H values between season (P<0.05). The Duncan's multiple range test of sediment p^H showed that the mean values of sediment p^H in the premonsoon was significantly different from the other seasons. The sediment pH exhibited asignificant correlation with the electrical conductivity and organic carbon of the sediment (Table II).

The mean values of the electrical conductivity of the sediment in the clam bed of Ashtamudi estuary is illustrated figure 4. In the premonsoon the mean values of sediment electrical conductivity varied from 3.03 ±2.094 mS/cm to 7.56 ± 4.455 mS/cm with an average of 5.32 ±3.267. In the monsoon the mean values fluctuated from 1.58 ±1.078 mS/cm to 6.59± 2.534mS/cm with an average of 5.10 ± 1.757. In the post monsoon the mean values deviated from 6.70 ± 3.495 to 7.22 ± 4.869 with an average of 7.03 ± 4.181. Statistical analysis showed that there was a significant spatio-temporal variation in sediment electrical conductivity. When the results of the electrical conductivity values obtained were subjected to analysis, significant differences in mean values of electrical conductivity were observed between the seasons (P< 0.000) and between the sites (P<0.000). The *DMRT* showed that the variations in postmonsoon values were significantly different from that of the monsoon and premonsoons. Sediment electrical conductivity exhibited significant positive correlation with phosphorus and negative correlation with sand fraction of sediment (Table I). The mean values of the electrical conductivity in different seasons at different sites of Kayamkulam estuary are sculptured in figure 4. In the premonsoon the sediment electrical conductivity values altered from 9.90 ± 6.06 mS/cm to 10.16 ± 5.4 mS/cm with an average of 10.02 ±5.7. In the monsoon the mean values varied from 4.54 ±1.186 mS/cm to 6.83 ± 5.26 mS/cm with an average of 5.6 ± 2.89. In the post monsoon the electrical conductivity values changed from 8.20 ± 3.871 to 8.75 ± 2.863 with an average of 8.48 ± 3.380. Statistical analysis revealed significant differences in electrical conductivity between seasons (P< 0.000). The *DMRT* showed that the variations were significant only in the monsoon. The sediment electrical conductivity displayed significant positive correlation with organic carbon and phosphorus content of sediment (Table II).

The average organic carbon values in the clam bed of Ashtamudi estuary is depicted in figure4. The mean values varied from 0.19 ± 0.187% to 0.59 ± 0.36% with an average of 0.412 ± 0.295 in the premonsoon. In the monsoon the organic carbon content fluctuated from 0.49 ± 0.413% and 0.71± 0.737 with an average of 0.585± 0.54. In the postmonsoon the mean values altered from 0.29± 0.175% to 1.13± 0.55% with an average of 0.73± 0.38.The statistical analysis showed that the mean values were significantly different between the seasons (P<0.003) and between the sites (P<0.005). *DMRT* of organic carbon at Ashtamudi estuary revealed that the value of postmonsoon was different from that of the other seasons. The organic carbon values presented a significant positive correlation with the phosphorus and silt fraction of the sediment and highly significant negative correlation with the sand fraction of the sediment (Table I). The figure 4 depicts the mean values and standard deviations of organic carbon in the Kayamkulam estuary. The mean organic carbon values varied from 0.73 ± 0.295% to 0.86± 0.495% with an average of 0.797 ± 0.388 in the premonsoon. In the monsoon the organic carbon content deviated from 0.32 ± 0.28% to 0.47± 0.187 with an average of 0.797± 0.387. In the postmonsoon the mean values of organic carbon altered from 0.59± 0.25% to 0.69± 0.76% with an average of 0.635 ± 0.46.The statistical analysis showed that there were significant difference in organic carbon values between the seasons (P<0.000).The *DMRT* showed that there were significant difference in organic carbon between the three seasons and it formed three subsets in three seasons. Organic carbon in the se4diment presented a significant positive correlation with phosphorus (Table II)

The spatio-temporal variation in the mean values nutrient phosphorus in the Ashtamudi estuary is presented in Figure 4. In the premonsoon the mean values of phosphorus varied from 0.90± 0.338 mg/g to 1.14± 0.422mg/g with an average of 1.034± 0.377. In the monsoon the mean values fluctuated from 0.97± 0.237 mg/g and 1.24± 0.294 mg/g with an average of 1.12 ±0.26. In the postmonsoon the mean values changed from 1.08± 0.198mg/g to 1.47± 0.441mg/g with an average value of 1.278 ±0.327 .The ANOVA of sediment phosphorus of the Ashtamudi estuary showed that there was significant variation in mean values of phosphorus between season (P<0.002) and between sites (P<0.001). The *DMRT* showed that the variation in the mean value of postmonsoon were significant when compared to the other seasons. The sediment phosphorus exhibited highly significant positive correlation with silt fraction of the sediment and negative correlation of sediment (Table I). The spatio-temporal variation in the mean values of nutrient phosphorus in the Kayamkulam estuary is outlined figure 4.In the premonsoon the mean values of phosphorus varied from 1.18± 0.67 mg/g to 1.39± 0.877mg/g with an average of 1.32± 0.72. In the monsoon the mean values differed from 1.36± 0.46 mg/g to 1.58± 0.23 mg/g with an average of 1.4565 ±0.34. In the postmonsoon the mean values ranged from 1.89± 1.04mg/g to 2.10± 1.29 mg/g with an average value of 1.99 ±1.17.The ANOVA of sediment phosphorus of the Kayamkulam estuary showed that there was significant variation in mean values of phosphorus between season (P<0.000) . The *DMRT* showed that the variation in the mean value of phosphorus in the postmonsoon was significant when compared to the other two seasons.

The mean values of potassium in the Ashtamudi estuary during the premonsoon varied from 2.31 ±1.252 mg/g to 2.61± 1.206 mg/g with an average of 2.5 ±1.3. In the monsoon the mean values fluctuated from 1.45± 1.334mg/g to 2.14± 1.045mg/g with an average of 1.77 ±1.097. In the postmonsoon the mean values altered from 1.31± 0.655mg/g to1.70± 0.512mg/g with an average of 1.514± 0.55 (Figure 4). The statistical analysis showed that there was significant variation in mean values of potassium between different seasons (P<0.000). The Duncan's multiple range tests showed that the variation in the premonsoon was significant when compared to the other seasons. The sediment potassium displayed a highly significant correlation with the clay fraction of the sediment (Table 1). The mean values of potassium in the clam bed of Kayamkulam estuary during the premonsoon changed from 2.26 ±0.492 mg/g to 2.45± 0.751 mg/g with an average of 2.35 ±0.62 (Figure 4). In the monsoon the mean values varied from 2.64 ± 1.75mg/g to 2.69± 1.64mg/g with an average of 2.654 ±1.36. In the postmonsoon the mean values fluctuated from 1.57 ± 0.52mg/g to 1.66± 0.528mg/g with an average of 1.62± 0.53. The statistical analysis showed that there were significant variation in mean values of potassium between different seasons (P<0.000). The Duncan's multiple range tests showed that the variations in the potassium values of postmonsoon was significant when compared to the other seasons.

E. Sediment variables-Difference between estuaries.

The Table III shows the variations in the mean values of the sediment variables (p^H, electrical conductivity, organic carbon, phosphorus, potassium) studied in the Ashtamudi estuary and Kayamkulam estuary. The mean values of sediment p^H recorded from the Ashtamudi estuary and Kayamkulam estuary were 6.34 ±1.23 and 6.56 ±1.25 respectively. The statistical analysis showed that the differences in mean values of sediment p^H between the estuaries were not significant. The mean value of sediment electrical conductivity recorded from the Ashtamudi estuary and Kayamkulam estuary were 5.48 ± 3.79mS/cm and 8.03 ± 4.49 mS/cm respectively. It was observed that the mean values of electrical conductivity of Ashtamudi estuary had significant variation when compared to the mean value of Kayamkulam estuary ($t_{(286)}$ =2.649, P=0.009). The mean values of organic carbon recorded in the Ashtamudi estuary and Kayamkulam estuary were 0.57± 0.504 % and 0.61± 0.41% respectively. The variations in mean values between the estuaries were not significant. The mean value of phosphorus recorded from the Ashtamudi estuary was 1.14± 0.356mg/g and that of Kayamkulam estuary was 1.59 ± 1.087mg/g. The mean values of nutrient phosphorus of Ashtamudi estuary had significant statistical difference when compared to the mean value of Kayamkulam estuary ($t_{(286)} = {}^{-}5.943$, P=0.000). The mean value of sediment potassium recorded from the Ashtamudi estuary was 1.93± 1.087mg/g and that of Kayamkulam estuary was 2.21± 0.988mg/g. It was observed that the mean values of sediment potassium of Ashtamudi estuary had statistically significant variation when compared to the mean value of Kayamkulam estuary ($t_{(286)} = {}^{-}2.275$, P=0.024).

The spatio-temporal variations in the sediment texture of clam beds at Ashtamudi estuary and Kayamkulam estuary are delineated in the Figure 6. In the premonsoon the sediment texture showed 69.42 ± 7.313% of sand, 13.71 ± 6.187 % silt and 16.87 ± 5.39% clay. In the monsoon the sand fraction was recorded as 74.42 ± 5.467%, silt fraction as 12.67 ± 5.17% and clay fraction as 12.91± 3.07%. In the postmonsoon 61.92 ± 12.563% of sand, 23.04 ± 10.72% of silt and 15.04 ±7.711% of clay were recorded in the sediment. The observed differences between seasons were significant for sand and silt content (P<0.05), but not for clay. The Sheperd –Ternary- Plot (Figure 6) of the sediment of clam beds at Ashtamudi estuary during the study period revealed that the sediment was sandy loam in all the sites observed in all the three seasons. In the premonsoon the textural analysis of Kayamkulam estuary produced 73.27 ±7.85% of sand, 14.05 ± 6.7 % silt and 12.68 ± 4.97% clay. In the monsoon the sand fraction was recorded as 69.15 ± 10.43%, silt fraction as 17.32 ± 6.06 % and clay fraction as 13.53± 7%. In the postmonsoon 67.04 ± 10.23% of sand, 16.88± 6.08 % of silt and 16.08 ±7.16% of clay were obtained in the sediment texture analysis. The observed differences between seasons were significant for sand fraction (P<0.05) than silt and clay. In the premonsoon the sediment type was noted as sandy loam in the sites I to III and loamy sand in the remaining sites (Figure 6). In the monsoon and postmonsoon sites I to III exhibited sandy clay loam texture and the sites IV to VI revealed loamy sand in nature. The variations in mean values between the estuaries were not significant (Table III).

F. Principal component analysis

The biplots of PC1 against PC2 of Ashtamudi estuary and Kayamkulam estuary showed the exact relation between biological parameter and the environmental parameters (Figure 7). Principal component analysis (PCA) of the data of Ashtamudi Estuary yielded five principal components (PCs) (Eigen values > 1). The five PCs together conferred 71.578 % of total variance in data. The first PC (PC1) accounted for 22.289 % of the total variance. It was due to very high positive loadings on sand (0.92) and high negative loadings on silt (-0.89). The second PC (PC2) achieved 18.311 % of total variance which was due to the high positive loadings on the water p^H (0.828), dissolved oxygen (0.762) and negative loadings on sediment p^H (-0.608), salinity (-0.521), temperature (-0.548). The third PC (PC3) was answerable for the 12.001 % of the total variance which was procured through the positive loadings on density of *Paphia malabarica* (0.763), electrical conductivity (0.684) and phosphorus (0.574).

The fourth PC (PC4) was responsible for 10.552 % of total variance which was due to the positive loadings on organic carbon (0.657) and negative loadings on clay (-0.69). The fifth PC (PC5) was responsible for 8.425 % of total variance which was due to the high positive loadings on potassium (0.874).PCA of data of the Kayamkulam estuary furnished five PCs (Eigen value >1). The five PCs together rendered 72.689 % of total variance. The first principal component (PC1) caused 22.444 % of total variance which was due to high loadings on sand (0.943) and negative loadings on clay (-0.808), silt(-0.824). The second PC (PC2) accorded 19.046 % of total variance which was due to positive loadings on sediment p^H(0.711), temperature(0.794) and negative loadings on dissolved oxygen (-0.628). The third principal component (PC3) contributed 14.182 % of total variance which was due to high positive loadings on electrical conductivity (0.836), organic carbon (0.777). The fourth principal component (PC4) explained 9.785 % of total variance it was due to positive loadings on density of clam, *Paphia malabarica* (0.745), salinity (0.736). The fifth PC (PC5) imparted 7.231 % of total variance which was due to high positive loadings on water p^H (0.841), potassium (0.694), phosphorus(0.533).

IV. DISCUSSION

The estuaries are often subjected to spatio-temporal variations in physico-chemical parameters which frequently range from freshwater to marine conditions. Since biotic species prefer different optimal conditions, the biota is spatially zoned along the gradient. The analysis of physico-chemical parameters influencing the abundance and distribution of clams clearly indicated the existence of significant relationship between the biological and environmental variables. According to Baron and Clavier (1992), the factors affecting the spatial distribution of benthic species are complex and were difficult to appraise. From the observations of the present study it was evident that there were significant spatio-temporal variations in the distribution of the clams in both the estuaries. These spatial variations in the distribution of clams may be due to the spatial variations in the environmental factors. The temporal variations were caused by the effect of water reaching the estuaries through the action of south west and north east monsoons.

Benthic sedentary and sessile species such as bivalve molluscs are not expected to exhibit a faster shift in their composition in response to changes in environmental parameters. Franz (1976) stated that the structure of benthic communities varies in conjunction with gradual changes along environmental gradients. A hydrodynamic gradient could be conditioning the spatial distribution of bivalve taxocene. Hence, in an estuary the distribution and density of clams were influenced by environmental changes. It has been reported that the environmental parameters such as salinity, temperature, sediment texture and organic content in the sediments significantly contribute to the abundance of bivalves (Lee, 1972).

The relationships between spatial and temporal patterns in clam density and distributions and the ambient factors such as salinity, water temperature, dissolved oxygen, water p^H, sediment texture, sediment p^H, organic carbon content, sediment nutrients phosphorus and potassium were measured during the study period. The analysis of density and distribution of the clam, *Paphia malabarica* in the Ashtamudi estuary and Kayamkulam estuary showed that the density and distribution patterns of the study period were best governed by salinity, dissolved oxygen, sediment organic carbon and sediment texture. The distribution of clams in the two estuaries was appeared to be zoned along the salinity and sediment gradient. However, a single environmental factor was not expected to be solely responsible for determining the distribution of the bivalves in the estuary. This is because the reactions of organisms to one environmental variable may be confounded by other prevailing environmental variables. Harkantra and Parulekar (1991) opined that no single factor could be considered as an ecological master factor that was totally responsible for community structure of macrobenthos. Wu and Richards (1981) and Owen and Forbes (1997) reported that changes in the structure of benthic communities in a subtropical estuary showed a good correlation with the prevailing gradient of increasing salinity.

In the present study, the hydrologic parameters that seemed to have the greatest influence on the density and distribution of the venerid clams *Paphia malabarica* was salinity and dissolved oxygen. The salinity values recorded showed the existence of a saline gradient departs from the mouth of the estuary to the upper reaches. On observing the distribution of clams it was observed that the clam *Paphia malabarica* being a euryhaline bivalve (Ram Mohan,1998) distributed in all the observed sites and their density was found decreasing from the barmouth to the sites in the upper reaches. The changes in water salinity affect a wide variety of biochemical and physiological processes in estuarine and marine bivalves. An increase or decrease in salinity often result in an increase or decrease of free amino acid levels in the tissues of marine bivalves, which are often monitored as a stress indicator (Powell *et al.*,1982 and Lee *et al*., 2004, Kube *et al.*, 2007).

Salinity was considered as a significant parameter to explain the variance in species distribution and abundance. The salinity profiles of the two estuaries (Figure 2 and 3) showed that wide fluctuations in salinity was mainly brought about by the south west monsoon and north east monsoon, land run off, riverine and tidal flow. These large salinity variations in an estuary increases physiological stress, which can result in the decreased density of species and restrict species distribution depending on species salinity tolerance thresholds (Edgar and Barrett, 2002; Manino and Montagna, 1977 and Zajac and Whitlatch, 1982). These findings were reflected in the present study too in the distribution of the estuarine bivalve species. The polyhaline *Paphia malabarica* was found in abundance in the high salinity sites. The same trend of bivalve distribution was observed by Harkantra and Rodrigues (2004) in Mandovi estuary. The results of the present study revealed that in both the estuaries the maximum clam densities were obtained in the premonsoon when the salinity values were recorded highest followed by the postmonsoon and least in the monsoon. In the monsoon the salinity was lowered to a level beyond the tolerance level of the estuarine clam. The decrease in salinity during the monsoon created perturbing environmental conditions in the estuaries. The unbalanced equilibrium created by monsoon stressed the clams in the estuaries. The decreased levels of dissolved oxygen and p^H augmented the effects of decreased salinity in the estuary especially in the lower reaches and this may be the reason for decreased density of the clam species in both the estuaries during the monsoon. These observations were justified by the findings of Ringwood and Keppler (2002). They suggested that the ability of the estuarine organism to tolerate salinity changes or dissolved oxygen stress may ultimately be related to the p^H conditions. Animals may be able to tolerate lower salinities or low dissolved oxygen conditions if p^H remains high but under low p^H conditions, tolerance will be diminished.

Sediment texture, sediment p^H and sediment electrical conductivity was most closely related to the abundance and distribution of clams in the present study. The sediment p^H during the monsoon and postmonsoon were lower than 6.5 in both the estuaries. In the Ashtamudi estuary it was further lowered and reached up to 5.55 in the monsoon especially in site I near barmouth. According to Vindograv *et al*. (1993) when p^H is lower than 6.8-6.9 calcium loss to the external environment exceeds gain. Low sediment p^H may also impair ion exchange (Hunter, 1990) and affect glutamate catabolism in the mitochondria of the bivalve mantle (Moyes *et al*., 1985). Therefore, low sediment p^H may have been the most important reason for low density of clams during the rainy season in the present study.

It was evident in the present study that the clam species followed the same trend in distribution pattern in both the estuaries. The clam, *Paphia malabarica* was widely distributed in the two estuaries and were present in all the sampling sites (sites I to VI) but, its density decreased from site near barmouth (site I) to the site near the upper reaches (site VI).According to Cahn (1951) the best substrates for bivalves usually contained 60-90 % sand. Coarse sediments usually contain little organic matter. Fine muddy sediments, in contrast, are usually characterized by a high organic content with a corresponding increase in abundance due to food availability. During the sampling period, a higher abundance of clams was found at sites characterised by fine sand and silt when compared to sites that constituted coarse sandy sediment. Hence it can be confirmed that the increased clam densities at these sites were due to the nature of the sediment and its high organic content.

Principal component analysis is an indirect gradient analysis that employs a linear response model, which is a simple approximation of the species response along an environmental gradient. The PCA of the data on the two estuarine systems during the study period generated a biplot (Figure 7) which showed that the density of the clam *Paphia malabarica* was placed close to variables such as salinity, organic carbon, silt fraction of the sediment and sediment p^H. Hence it can be assumed that these variables might exert an upper hand on the density and distribution of the clam *Paphia malabarica*. Salinity values with water temperature and density of clams were increased from October to May which emphasised strong relation between the clams and environmental factors. Mahapatro *et al.* (2011) were also of similar opinion. Vizakat (1991) opined that in tropical waters, salinity is the most influencing parameter over benthic productivity. Same observation was made in the present study from the factor loadings of the principal component analysis that showed salinity, sediment texture and p^H as major guiding factors.

The statistical analysis showed significant differences in clam densities between the two estuaries. The Ashtamudi estuary was denser than the Kayamkulam estuary. These variations in clam densities may be due to the variations in their depth. This was supported by the findings of Mahapatro *et al.* (2011). He quoted that there was a clear evidence of increasing rate of population density and deeper regions than the shallow depth. This was because in shallow regions occur high turbidity, often fluctuations of environmental parameters and more fishing pressure disturb habitat conditions, while in deeper regions favouring conditions were existed due to stable environmental conditions. Similar results were observed by Ingole *et al*. (2010) in the shelf regions of Arabian sea. Nichols(1970) and Flint and Rabalais (1980) were of opinion that in shallow marine environments sedimentary or other physical variables that vary with depth were more likely to be the controlling factors than the depth itself.

V. CONCLUSION

The present results showed spatio-temporal variations in the density and distribution of the clam *Paphia malabarica* in the two estuaries in relation to the spatio-temporal variations of the environmental factors. The two estuaries exhibited the same trends in environmental variations. But the observations on the density and distribution of the clam showed that the two Lake systems differ significantly in the abundance of the clam even though it was influenced by similar environmental variables. The Ashtamudi Lake is denser than the Kayamkulam Lake. This difference may be attributed to the depth of the lake system. Ashtamudi Lake is deeper than the Kayamkulam Lake. In Ashtamudi Lake there is a ban in the clam fishery from November to February every year coinciding with the spawning season of the clam which is not practiced at Kayamkulam Lake. More than this there is intense sand mining near the barmouth of Kayamkulam estuary which destroys the clam bed of that region. These findings throw lights on the fact that the species distribution in a habitat is influenced by both the environmental factors as well as the anthropogenic activities prevalent in that habitat.

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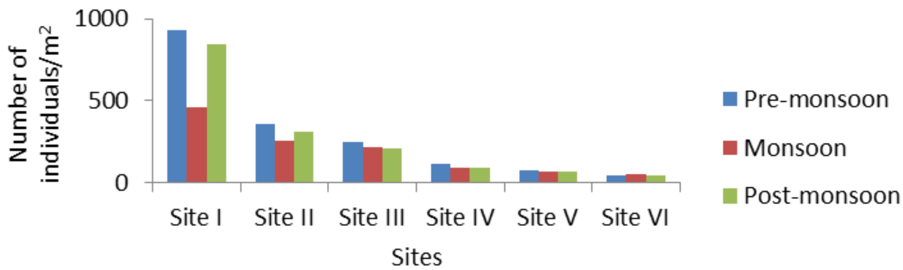
a.



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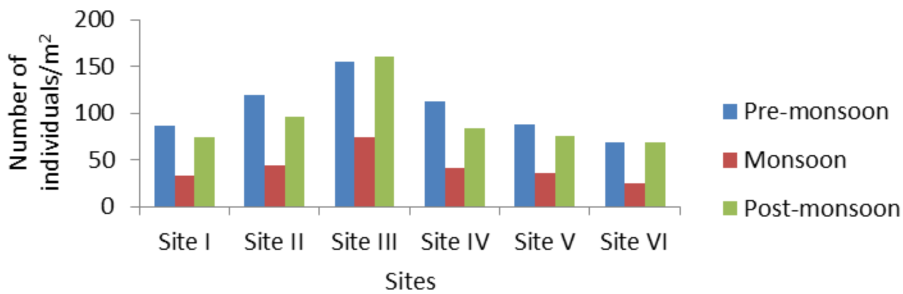

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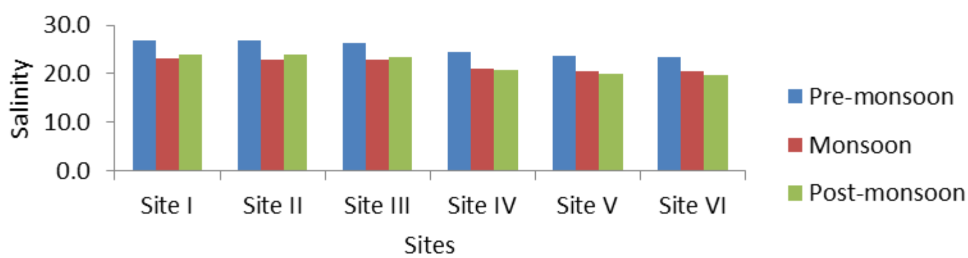
Figure 1: Density of clam *Paphia malabarica* in the clam beds (a)Ashtamudi Lake. (b)Kayamkulam Lake.

c.



season,$p<0.004$

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season,$p<0.003$ sites,$p<0.004$

e.

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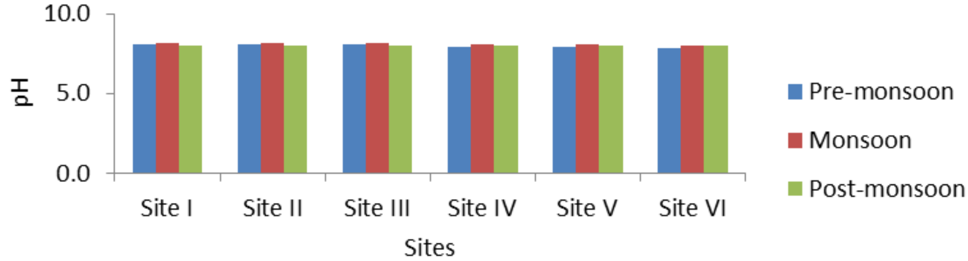

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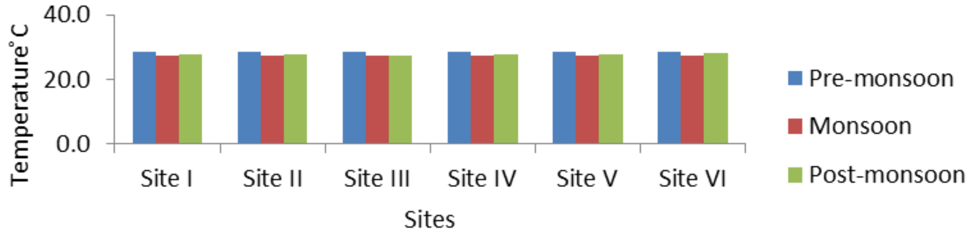

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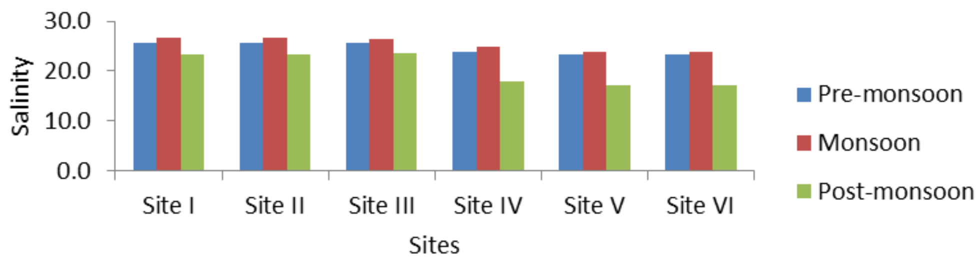
Figure 2: Hydrographic parameters of the clam bed of Ashtamudi Lake

g.



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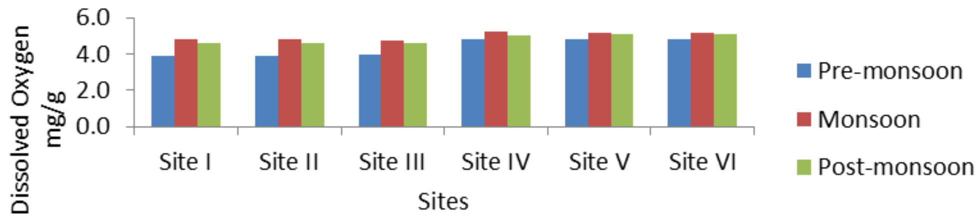
h.



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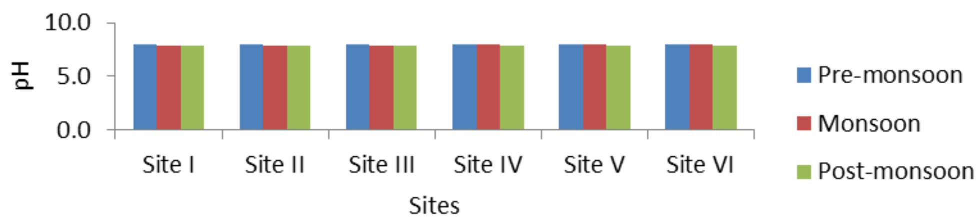
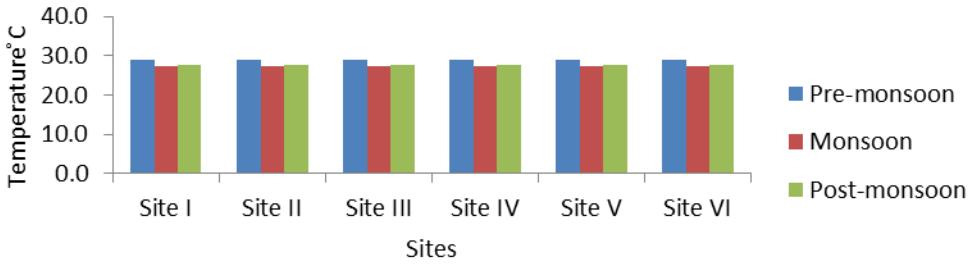
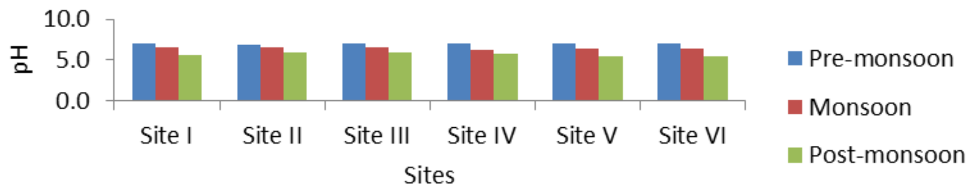


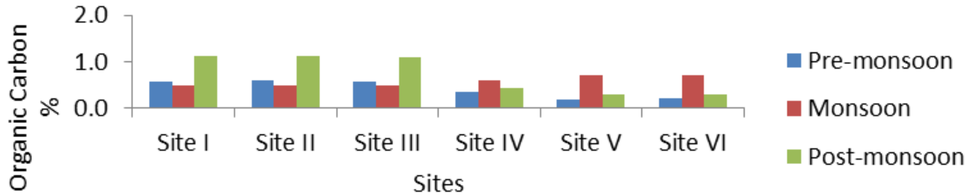


d. season,p<0.000

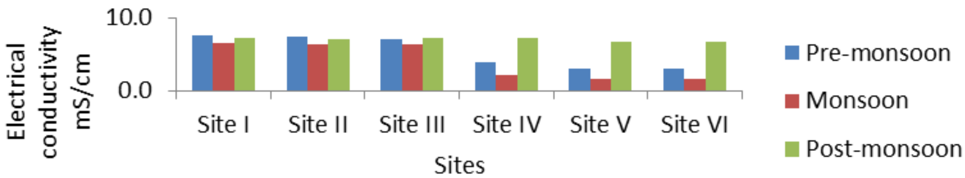
Figure 3: Hydrographic parameters of the clam bed of Kayamkulam Lake



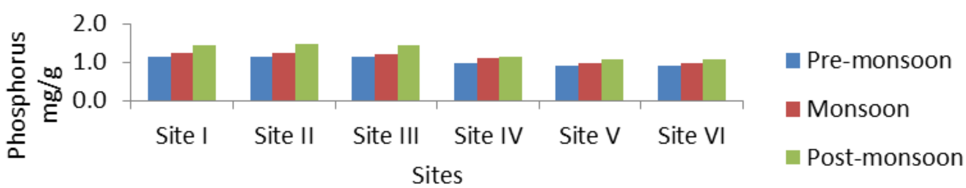
a. season,p<0.000



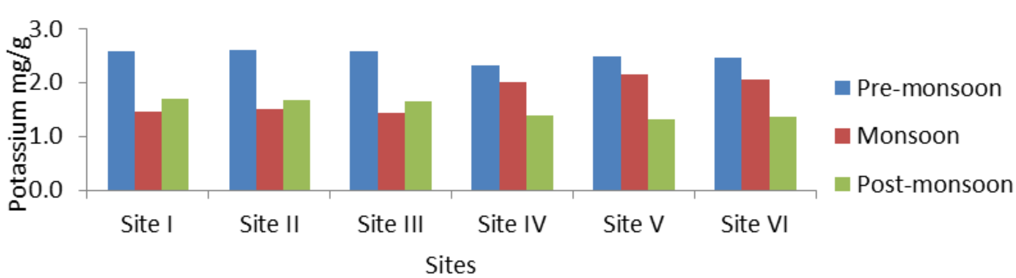
b. season,p<0.003 sites,p<0.005



c. season,p<0.000 sites,p<0.000

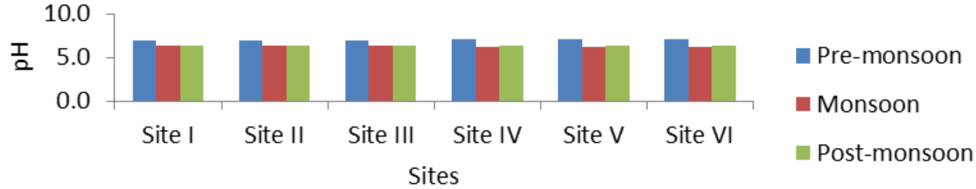


d. season,p<0.001 sites,p<0.001

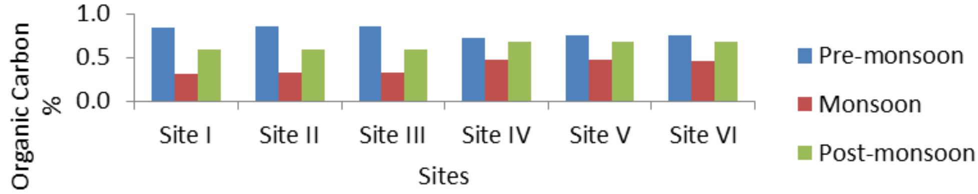


e. season,p<0.000

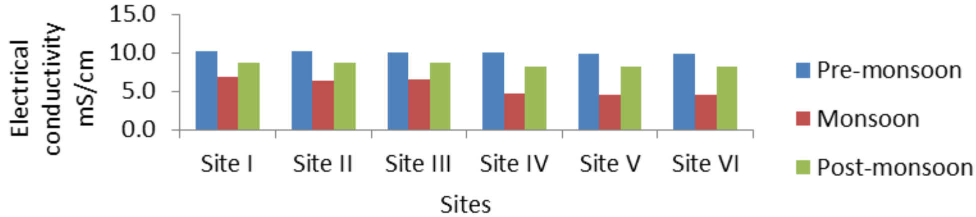
Figure 4: Sediment parameters of clam bed of Ashtamudi Lake



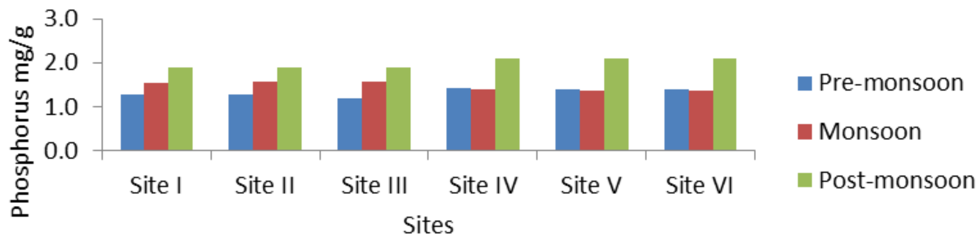
a. season,p<0.010



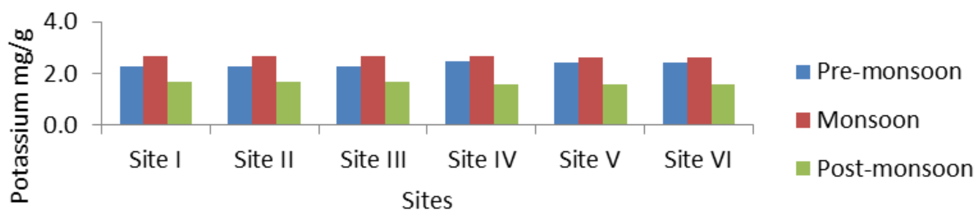
b. season,p<0.000



c. season,p<0.000



d. season,p<0.000



e. season,p<0.000

Figure 5: Sediment parameters of clam bed of Kayamkulam Lake

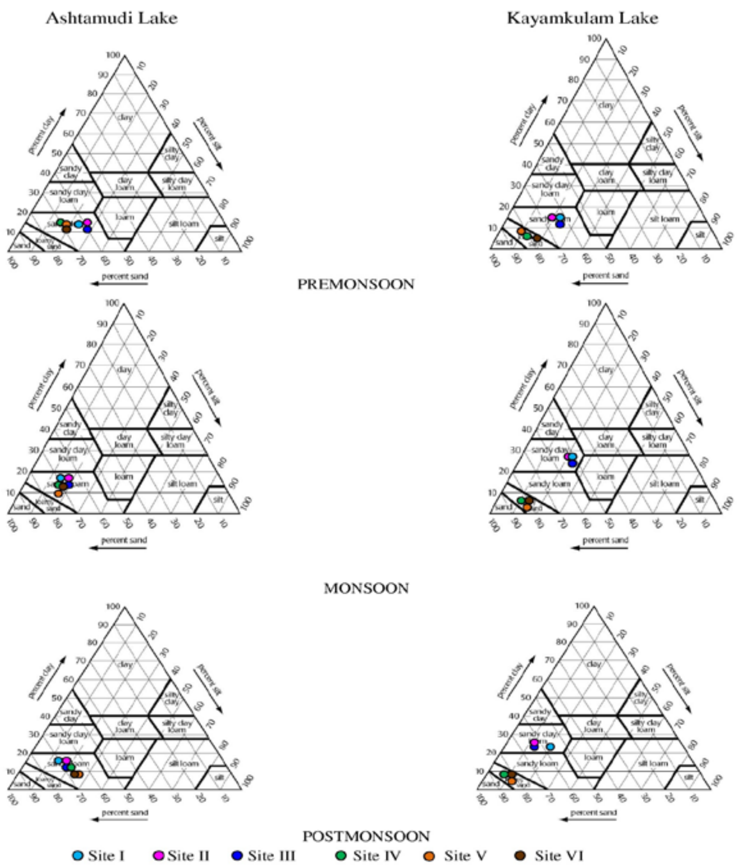
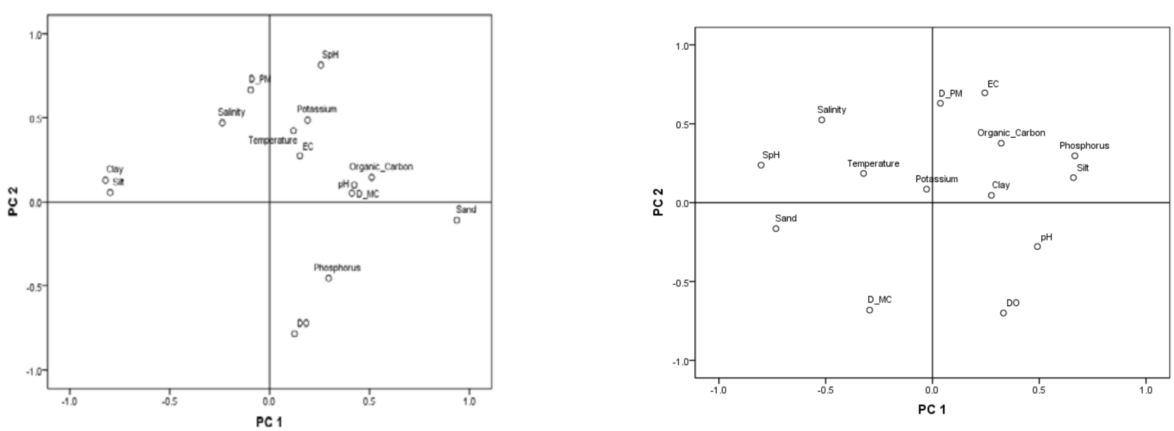


Figure 6: Soil types of the clam beds at Ashtamudi Lake and Kayamkulam Lake



a.Ashtamudi Lake **b.Kayamkulam Lake**

Figure 7: The biplot of PC1 against PC2 showing the relation between environmental and biological parameters in the clam beds.

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.000												
2	-0.456**	1.000											

3	-0.216**	0.518**	1.000										
4	0.122	-0.248**	-0.328**	1.000									
5	0.430**	-0.357**	-0.463**	0.215**	1.000								
6	0.210*	-0.319**	-0.019	0.077	-0.015	1.000							
7	0.161	-0.109	0.015	-0.182*	-0.196*	0.157	1.000						
8	-0.284**	0.013	0.194*	-0.220**	-0.495**	0.473**	0.187*	1.000					
9	0.197*	-0.042	0.138	-0.016	0.093	0.132	0.030	-0.035	1.000				
10	0.272**	0.012	-0.076	-0.017	0.440**	-0.212*	-0.224**	-0.287**	-0.075	1.000			
11	-0.220**	-0.007	-0.031	-0.074	-0.422**	0.164	0.329**	0.278**	-0.070	-0.824**	1.000		
12	-0.141	-0.010	0.182*	0.143	-0.124	0.122	-0.110	0.078	0.239**	-0.494**	-0.087	1.000	
13	0.218**	-0.227**	0.084	-0.003	0.139	0.305**	0.157	0.198*	-0.038	0.040	-0.032	-0.021	1.000

Table I: Correlation matrix of environmental and biological parameters of the clam bed at Ashtamudi Lake. 1=salinity:2=dissolvedoxygen:3=Waterp^{H}:4=temperature:5=Sedimentp^{H}:6=electricalconductivity:7=organic carbon:8=phosphorus:9=potassium:10=sand:11=silt:12=clay:13=Clam density.

Table II: Correlation matrix of environmental and biological parameters of the clam bed at Kayamkulam Lake.

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.000												
2	-0.256**	1.000											
3	-0.046	-0.033	1.000										
4	0.020	-0.224**	-0.131	1.000									
5	0.147	-0.631**	0.177*	0.304**	1.000								
6	0.118	-0.302**	0.054	-0.115	0.264**	1.000							
7	0.068	-0.137	0.203*	0.098	0.208*	0.458**	1.000						
8	-0.158	0.235**	0.450**	-0.360**	-0.347**	0.191*	0.445**	1.000					

9	0.205*	-0.320**	0.320**	0.127	0.285**	0.029	0.051	0.113	1.000				
10	-0.226**	0.243**	0.221**	0.097	0.144	-0.008	0.309**	0.120	0.059	1.000			
11	0.102	-0.144	-0.073	0.021	-0.164*	-0.169*	-0.357**	-0.104	0.018	-0.847**	1.000		
12	0.278**	-0.269**	-0.297**	-0.178*	-0.089	0.164*	-0.188*	-0.104	-0.112	-0.880**	0.494**	1.000	
13	0.351**	-0.293**	0.018	0.138	0.415**	-0.027	-0.070	-0.407**	0.302**	-0.104	0.121	0.062	1.000

1=salinity:2=dissolvedoxygen:3=Waterp^H:4=temperature:5=Sedimentp^H:6=electricalconductivity:7=organic carbon:8=phosphorus:9=potassium:10=sand:11=silt:12=clay:13=Clam density.

Table III: Variation in mean values of environmental parameters and biological parameters at Ashtamudi estuary and Kayamkulam Estuary

Variables	Location	Mean	SD	Mean Difference	t - value	df	p - value
Salinity	AE	23.04	5.727	-0.39	-0.548	286	0.584
	KE	23.43	6.347				
Dissolved Oxygen mgl^{-1}	AE	4.48	1.792	-0.262	-1.328	286	0.185
	KE	4.74	1.543				
Water p^H	AE	8.02	0.239	0.088	2.649	286	0.009*
	KE	7.94	0.32				
Temperature	AE	27.89	1.195	-0.036	-0.227	286	0.82
	KE	27.93	1.488				
Sediment p^H	AE	6.34	1.233	-0.214	-1.462	286	0.145
	KE	6.56	1.249				
Electrical conductivity	AE	5.48	3.797	-2.548	-5.195	286	0.000*
	KE	8.03	4.495				
Sediment Organic Carbon	AE	0.57	0.504	-0.034	-0.634	286	0.527
	KE	0.61	0.411				
Sediment Phosphorus	AE	1.14	0.356	-0.449	-5.943	286	0.000*
	KE	1.59	0.833				
Sediment Potassium	AE	1.93	1.087	-0.279	-2.275	286	0.024*
	KE	2.21	0.988				
Sand	AE	68.58	9.921	-1.208	-0.817	286	0.415
	KE	69.79	14.725				
Silt	AE	16.47	8.661	0.396	0.402	286	0.688
	KE	16.08	8.033				
Clay	AE	14.94	5.649	0.813	0.918	286	0.359
	KE	14.13	8.993				

Density of clam	AE	5.02	0.982	0.876	8.368**	286	0.000*
	KE	4.15	0.784				

AE=Ashtamudi estuary:KE=Kayamkulam estuary:SD= standard deviation:df=degrees of freedom