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Distribution and Abundance of Zooplankton in Estuarine Regions along the Northern Kerala, Southwest Coast of India

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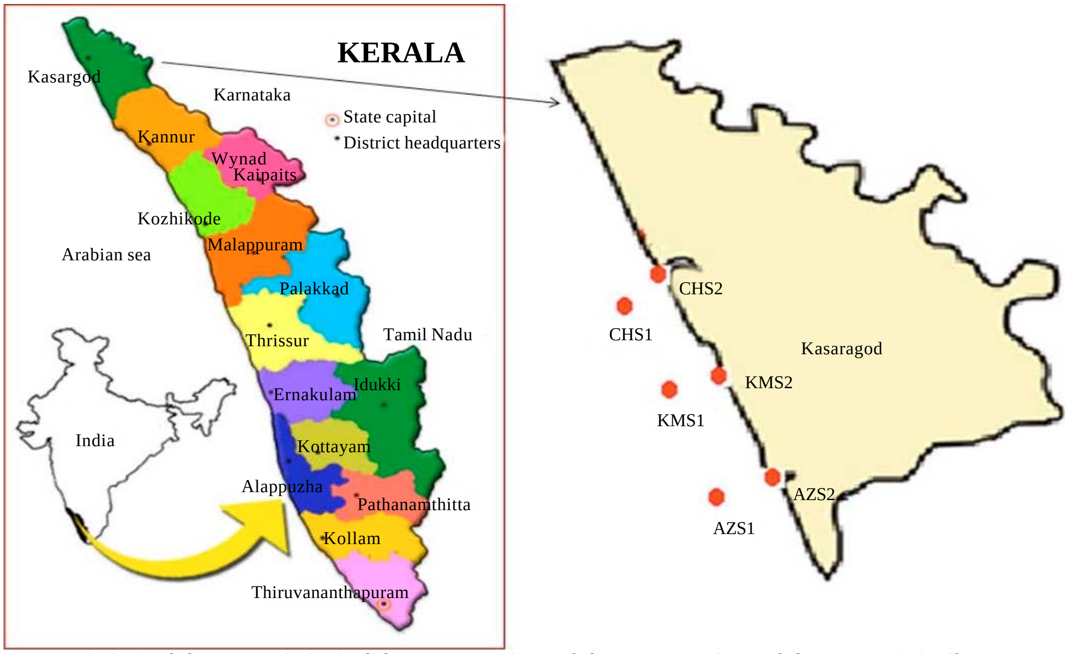
ABSTRACT
Zooplankton plays an important role in the marine food chain as intermediate link between phytoplankton and fish. Many of them are known to play important roles in marine ecosystems, including those in the food chain and matter transfer but there are also many species whose distribution and ecology are mostly unknown. The present study accounts deals with aspect of distribution and tidal influence of zooplankton from Estuarine regions along the Northern Kerala. The samples were taken in horizontal hauls using Hydro-Bios net (15 μm mesh size and 0.5 m mouth diameter) during high and low tide. The zooplankton community consisted of 65 species. Copepoda was the most important group both in term of species number and abundance. The species documented during low tide belong to groups with average percentage composition (%) such as calonoidia (25.37), cyclopodia (7.87), Harpacticoida (10.82), copepodites (18.11), foraminifera (1.99), ciliata (18.11), chaetognatha (2.88), cladocera (6.82), isopods (2.8) and larvae (13.28). While during high tide (%) groups include calonoidia (29.34), cyclopodia (4.69), Harpacticoida (4.38). The remaining groups viz., ctenophore, doliolids, siphonophores, isopods, ostracoda, cladocera, ctenophore, decapoda and fish eggs occurred sporadically and in small numbers. The highest abundance (1096 No. L^{-1}) was observed during high tide from Azhlithala-Station 2, while the lowest (117 No. L^{-1}) was detected during high tide from Chittari palam-Station 2. Both diversity and evenness was higher in Azhithala-Station 1 during high tide whereas the lowest diversity was observed during low tide from Chittari palam-Station 2 and no significant differences in dominance and total taxa of the studied area. The significant negative correlation obtained between the zooplankton density and evenness (-0.954) while positive correlation (0.993) obtained between diversity index and evenness. Further, multivariate analysis such as cluster analysis and PCA was engaged to correlate the zooplankton diversity. These analyses afford a superior significant in similarity and dissimilarity with in zooplankton community and studied sites.

Key words: Zooplankton, Estuarine, composition, abundance, multivariate analysis

INTRODUCTION
The planktons are two categories, the phytoplankton which includes all the minute photosynthetic floating organisms and the zooplankton by animal groups. Zooplankton forms a major link in the energy transfer in the aquatic biosphere and their ecology is of considerable interest in assessing the production potential of the sea. The fishery exhibits marked fluctuations



AZS1: Azithala station 1, AZS1: Azithala station 2, KMS1: Kumbala station 1, KMS2: Kumbala station 2, CHS1: Chittari palam station 1, CHS2: Chittari palam station 2

Fig. 1: Map showing the study area

from season to season and from year to year. Fisheries production is influenced mainly by biological factors, especially phytoplankton and zooplankton abundance which are intern controlled by physico-chemical factors. Aspects of zooplankton ecology form varies habitats such as mangroves, estuaries, coastal waters, corals lagoons and open oceans are worth considering, as they serve the dynamic nature of marine environment. In an area where several water bodies mix the planktonic animal alone can give the clue as to the waters origin unless the salinity differences are marked (Russell, 1935).

Many marine organisms, including most commercially-important species of fish, depend on estuaries at some point during their development (Carlsson *et al.*, 1995). Because many species of fish and wildlife rely on the sheltered waters of estuaries as protected spawning places, estuaries are often called the "nurseries of the sea".

Zooplankton constitutes the largest ecological group organisms in the sea and plays an important role in marine food chain. They feed on phytoplankton and in turn form the food for animals at higher trophic level. The rate of zooplankton production can be used as a tool to estimate the exploitable fish stock of an area (Tiwari and Nair, 1991). Study of Estuarine zooplankton population, the secondary producers plays a crucial role in food chain regulation of Estuarine ecosystem. Many workers have been extensively studied the species composition and seasonal distribution of zooplankton in the mangrove waters and estuaries both East and West coasts of India (Dalal and Goswami, 2001; Santhanam and Perumal, 2003; Saravanakumar *et al.*, 2007; Mathivanan *et al.*, 2007; Perumal *et al.*, 2009; Shanthi and Ramanibai, 2011; Prabhahar *et al.*, 2011; Santhanam *et al.*, 2012). However, the information on zooplankton diversity from the Estuarine waters of North Kerala is still scanty. Hence, the present study was undertaken on species composition, distribution and diversity of zooplankton from various Estuarine regions along the Northern Kerala. Three study sites were fixed along the estuary (Fig. 1).

MATERIALS AND METHODS

Three seasonal samplings were carried out during the months of post monsoon (December 2013) and summer (March, 2014) in the selected Estuarine region along the Kasaragod district, North Kerala. Zooplankton and water samples were collected during high tide and low tide from the study area.

Surface zooplankton samples were collected using Hydro-Bios zooplankton net (250 µm mesh size, 0.5 m diameter, 1.8 m length) fitted with a Hydro-Bios digital flow meter. Surface hauls were made from the stern side of boat which maintained at a speed of 0.8 nautical miles per hour, for ten minutes. The collected zooplankton was transferred to 500 mL polythene containers and preserved using 5% buffered formalin. The preserved samples were transferred into large Petri dishes and the macro zooplankton like Hydromedusa and large fish larvae were removed. The total numbers of organisms were enumerated in Sedgewick rafter plankton counting chamber under compound microscope. The zooplankton was identified following Davis (1955), Kasturirangan (1963), Wimpenny (1966), Smith (1977), Newell and Newell (1986), Todd and Laverack (1991) and Perumal *et al.* (1998).

For quantitative analysis, the known quantity of zooplankton samples were placed on the counting chamber and counted under light microscope. Biodiversity indices such as species diversity (H), evenness (J) and richness (SR) were calculated by using diversity software package (Diversity infra) following the standard formulae (Shannon and Wiener, 1949; Pielou, 1966; Gleason, 1922).

Shonon and weavers equation is:

$$H' = \left[-\sum_{i=1}^{S} Pi\log_2 Pi.... \right]$$

where, H' is species diversity in the bits of information per individual and Pi is proportion of the sample belong to the species. Species Richness (SR) was calculated as described by Gleason (1922):

$$SR = \left[\frac{S-1}{\log_e N} \right]$$

where, S is the number of species of particular sample and N is the natural logarithm of the total number of individuals of all the species in the sample.

Evenness index (J') (equitability) was calculated by the formula of Pielou (1966):

$$J' = \left[\frac{H'}{\log_2 S} \right]$$

where, H' is species diversity in the bits of information per individual and S is number of species.

Dominant index (δ) was calculated using the formula of McNaughton (1967) as described by Ignatiades and Mimicos (1977):

$$\delta = \left[100 \, \frac{(n_1 + n_2)}{N} \right]$$

where, δ is dominance index, equal to the percentage of total standing crop contributed by the two most important species n_1 and n_2 is percentage of total population of total phytoplankton standing crop in the same series of sample.

Simple correlation coefficient was used for interpretation. Multivariate analysis such as cluster analysis and PCA was engaged to correlate the zooplankton.

Statistical analysis

Data preparation: All data were compressed as species level and reviewed for any errors. The compacted data were arranged as matrix by taking species as a variables and collection sites as a rows. In order to reduce the heteroscedasticity in the data, the data was log transformed followed by standardized. Standardization is a procedure which removes the magnitude differences between variables. In the present study Z-score transformation procedure was used to normalize the value of each variable. The standardized data was used for the further Cluster Analysis (CA) and Principal Component Analysis (PCA).

RESULTS

Physical parameters

Depth: The depth at Estuarine sampling locations recorded were from 3.0-7.5 m with an average of 5.76±1.39 m during low tide sampling and from 3.5-8.0 m with an average of 6.25±1.43 m during high tide, respectively (Fig. 2).

Atmospheric temperature: The atmospheric temperature during low tide fluctuated between 27.2 and 31.00°C with an average of 30.71±1.22°C and during high tide it fluctuated between 26.09 and 31.05°C with an average of 30.71±0.62°C (Fig. 3).

Surface seawater temperature: The surface seawater temperature varied from 27.00-30.05°C with an average of 29.86±0.4°C during low tide. During high tide the temperature was recorded between 26.00 and 30.05°C with an average of 29.88±0.49°C (Fig. 4).

pH: The pH value of sea water was observed from 7.04 to 8.01with an average of 7.08±0.23 during low tide and from 7.03 to 8.03 with an average of 7.73±0.39 during high tide (Fig. 5).

Salinity: The salinity of water was observed to be within the range between 29.05 and 32.00 PSU with an average of 30.58±0.99 PSU during low tide and between 30.09 and 33.00 PSU with an average of 31.16±0.30 PSU during high tide (Fig. 6).

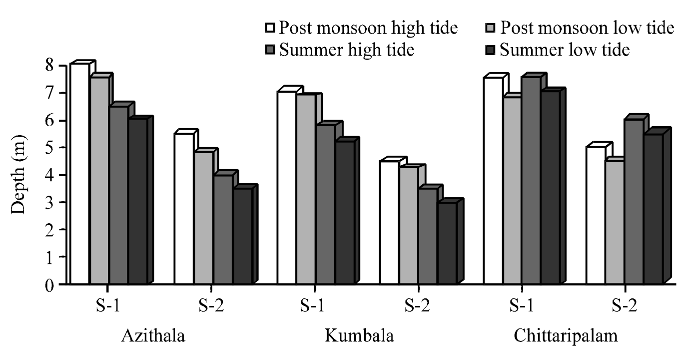


Fig. 2: Seasonal variations of depth recorded from different Estuarine

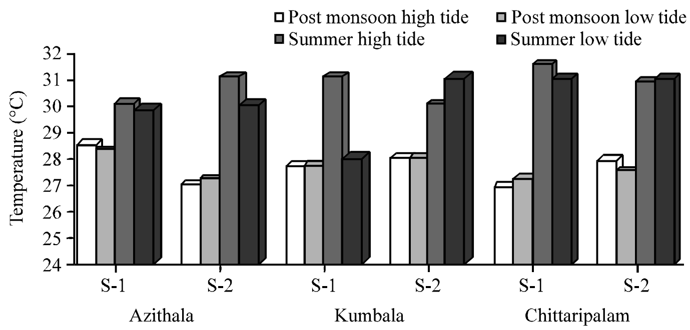


Fig. 3: Seasonal variations of atmospheric temperature recorded from different Estuarine

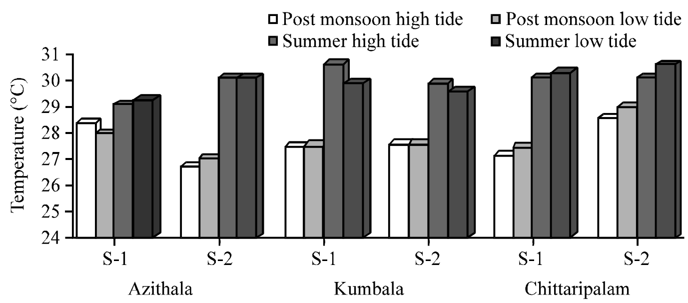


Fig. 4: Seasonal variations of water temperature recorded from different Estuarine

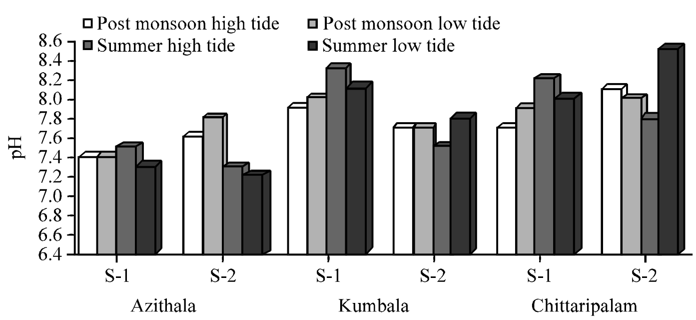


Fig. 5: Seasonal variations of water pH recorded from different Estuarine

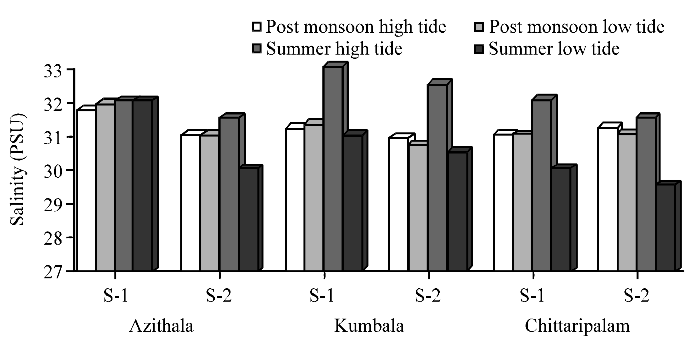


Fig. 6: Seasonal variations of salinity recorded from different Estuarine

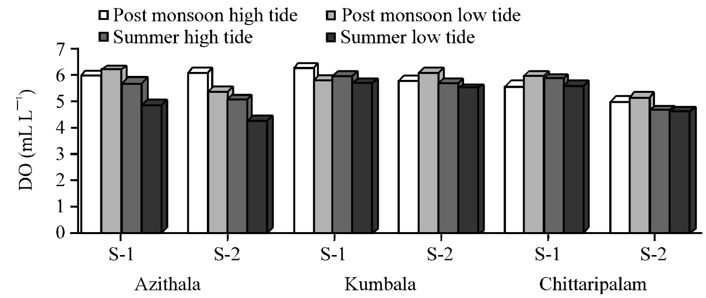


Fig. 7: Seasonal variations of DO recorded from different Estuarine

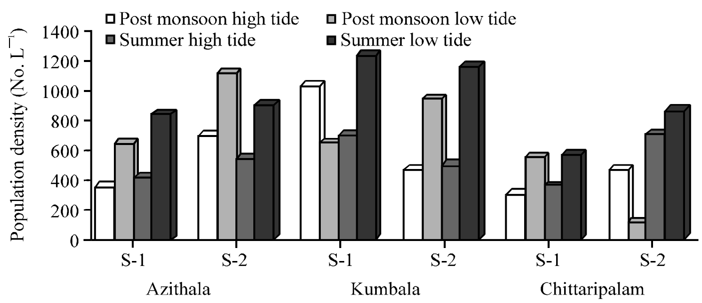


Fig. 8: Seasonal variations of zooplankton population density recorded from different Estuarine

Dissolved Oxygen (DO): The DO concentrations ranged from 4.02 to 6.01 mL L^{-1} with an average of 5.68±0.40 mL L^{-1} and from 4.02 to 6.20 mL L^{-1} with an average of 5.07±0.49 mL L^{-1} during low and high tides, respectively (Fig. 7).

Biological parameters

Species composition: Totally 53 species of zooplankton were identified in the present investigation at Estuarine waters (Table 1). Of these, calonoidia (13), ciliate (8), cyclopodia (6), Crustacean larval forms (3), Harpacticoida (3), foraminifera (3), mollusca (2), chaetognatha (2), siphonophores (1). The remaining groups viz., copepodite, ctenophore, doliolids, isopods, ostracoda, cladocera, ctenophore, decapoda and fish larvae occurred less in small numbers (Table 1).

Percentage composition: Among the zooplankton Calanoid copepods were found to dominant followed by Cyclopoida and Harpacticoida. The species documented during low tide belong to groups with average percentage composition (%) such as calonoidia (25.37), cyclopodia (7.87), harpacticoida (10.82), copepodites (18.11), foraminifera (1.99), ciliata (18.11), chaetognatha (2.88), cladocera (6.82), isopods (2.8) and larvae (13.28) (Table 2).

While during high tide (%) groups include calonoidia (29.34), cyclopodia (4.69), harpacticoida (4.38). The remaining groups viz., ctenophore, doliolids, siphonophores, isopods, ostracoda, cladocera, ctenophore, decapoda and fish eggs occurred sporadically and in small numbers (Table 3).

Zooplankton population density: Zooplankton population density in Estuarine ranged from 300 to 1015 No. L^{-1} with an average of 544±139 No. L^{-1} and from 117 to 1218 No. L^{-1} with an average of 658±363 No. L^{-1} during low and high tides, respectively (Fig. 8).

Table 1: Checklist of zooplankton recorded in the Estuarine waters

Phylum protozoa (protozoans)
Foraminifera
Acantharia
Acanthochiasma sp.
Globigerina bulloides
Ciliata
Tintinnopsis minuta
T. cylindrical
T. directa
T. tubulosa
T. turbinate
Favella brevis
F. phillippensis
Phylum cnidaria (cnidarians)
Medusae
Jelly fish
Rhizostoma sp.
Shiphonophore
Porpita porpita
Phylum annelida (segment worms)
Polychaeta
Sabellarid larvae
Tomopteris sp.
Nematode
Phylum mollusca (mollusks)
Gastropod velliger*
Bivalve velliger
Phylum arthropoda (crustacean)
Calanoida
*Acartia spinicuda**
*A. danae**
Acrocalanus gracilis
A. gibber
Calanus finmarchicus
Centeropages furcatus
Eucalanus tergestina
E. attenuatus
E. crassus
*Paracalanus parvus**
Pontello psisherdmani
Pseudocalanus elongates
*Nannocalanus minor**
Cyclopoid
Copilia vitrea
Corycacus danae
C. speciosus
C. catus
Oithona brevicornis
*O. rigida**
*O. similis**
Harpacticoida
*Euterpina acutifrons**
Miracia efferata
Macrosetella norvigeca

Table 1: Countinue

Crustacean larval forms
Copepodite*
Cybris larvae of Barnacle
Zoea-crabs
Prawn larvae
Decapoda
Lucifer sp.
Isopods
Ctenophore
Cladocera
Evadena tergestina
Ostracoda
Phylum chaetognatha (arrow worms)
Sagitta enflata
S. hamata
Phylum chordata (chordates)
Appendicularians
Oikopleura dioica
Oikopleura sp.
Doliolids
Pisces
Fish egg
Fish larvae

*Dominant species observed from the study sites

Table 2: Percentage composition of zooplankton during low tide

Stations	AZ-S1-LT	AZ-S2-LT	CH-S1-LT	CH-S2-LT	KM-S1-LT	KM-S2-LT	Avg
Foraminifera	0.00	2.66	1.66	3.80	1.370	2.44	1.99
Acantharia	0.00	1.33	0.00	0.00	1.370	0.00	0.45
Ciliata	14.32	9.33	0.00	0.00	7.600	0.00	5.20
Siphonophores	0.00	0.00	0.00	0.00	0.680	0.00	0.11
Ctenophore	0.00	0.00	0.00	0.00	1.370	0.00	0.22
Doliolids	0.00	0.00	0.00	0.00	1.370	0.00	0.22
Chaetognatha	4.09	1.33	4.70	3.80	3.400	0.00	2.88
Cladocera	2.05	6.66	5.00	13.93	4.800	8.50	6.82
Isopods	2.05	0.00	3.33	0.00	4.130	7.32	2.80
Ostracoda	2.05	0.00	1.66	0.00	1.370	2.44	1.25
Copepodites	0.00	0.00	0.00	15.20	43.440	50.02	18.11
Calonoidia	22.50	30.66	46.66	46.87	5.517	0.00	25.37
Harpacticoida	16.36	10.66	11.70	3.80	4.130	18.30	10.82
Cyclopodia	14.31	12.00	13.33	7.60	0.000	0.00	7.87
Appendicularians	2.05	0.00	1.66	0.00	0.680	0.00	0.73
Siphonophores	0.00	0.00	0.00	0.00	0.000	0.00	0.00
Ctenophore	0.00	0.00	0.00	0.00	0.000	0.00	0.00
Doliolids	0.00	0.00	0.00	0.00	0.000	0.00	0.00
Decapoda	2.05	1.33	0.00	0.00	1.400	2.44	1.20
Larvae	18.41	24.10	11.66	2.53	14.480	8.54	13.28
Fish eggs	0.00	0.00	0.00	7.60	0.000	0.50	1.35

Zooplankton species diversity: Zooplankton species diversity in Estuarine ranged from 2.06 to 4.10 with an average of 3.27±0.77 and from 2.73 to 4.57 with an average of 3.7±0.56 during low and high tides, respectively (Fig. 9).

Table 3: Percentage composition of zooplankton during high tide

Stations	AZ-S1-HT	AZ-S2-HT	CH-S1-HT	CH-S2-HT	KM-SI-HT	KM-S2-HT	Avg
Foraminifera	2.94	1.77	1.28	0.00	1.11	3.75	1.81
Acantharia	1.47	0.88	2.56	0.00	2.22	4.51	1.94
Ciliata	10.30	5.31	11.53	13.60	2.20	8.30	8.54
Siphonophores	2.94	0.00	0.00	0.00	2.22	0.00	0.86
Ctenophore	1.47	0.00	0.00	0.00	3.33	0.00	0.80
Doliolids	1.47	0.89	0.00	0.00	2.22	0.00	0.76
Chaetognatha	4.41	5.31	3.84	4.80	3.33	0.00	3.62
Cladocera	10.30	9.98	0.00	0.00	2.22	0.00	3.75
Isopods	1.47	0.89	1.28	4.08	1.11	2.25	1.85
Ostracoda	1.47	44.25	2.56	1.36	1.11	4.51	9.21
Copepodites	0.00	0.00	0.00	0.00	4.44	37.50	7.01
Calonoidia	33.84	5.31	41.02	36.74	45.55	13.50	29.34
Harpacticoida	7.35	4.42	7.69	6.80	0.00	0.00	4.38
Cyclopodia	2.94	0.00	10.25	14.96	0.00	0.00	4.69
Appendicularians	2.94	0.89	1.28	0.68	12.20	0.00	3.00
Siphonophores	0.00	0.00	0.00	3.40	0.00	0.00	0.57
Ctenophore	0.00	0.00	0.00	2.72	0.00	0.00	0.45
Doliolids	0.00	0.00	0.00	3.40	0.00	0.00	0.57
Decapoda	1.47	0.89	1.28	0.68	3.30	0.00	1.27
Larvae	13.24	20.36	12.82	6.80	17.70	25.56	16.09
Fish eggs	0.00	0.00	0.00	0.00	0.50	0.00	0.08

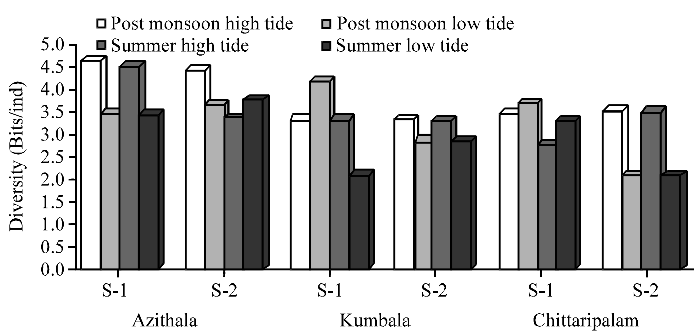


Fig. 9: Seasonal variations of zooplankton diversity recorded from different Estuarine

Zooplankton evenness: Zooplankton Evenness in Estuarine ranged from 0.52 to 1.31 with an average of 0.98±0.30 and from 0.85 to 2.10 with an average of 1.08±0.40 during low and high tides, respectively (Fig. 10).

Zooplankton dominance: Zooplankton dominance in Estuarine ranged from 0.41 to 0.26 with an average of 0.10±0.08 and from 0.05 to 0.11 with an average of 0.81±0.02 during low and high tides, respectively (Fig. 11).

Zooplankton taxa: Zooplankton taxa in Estuarine ranged from 15 to 46 with an average of 29±11 and from 18 to 46 with an average of 30±10 during low and high tides, respectively (Fig. 12).

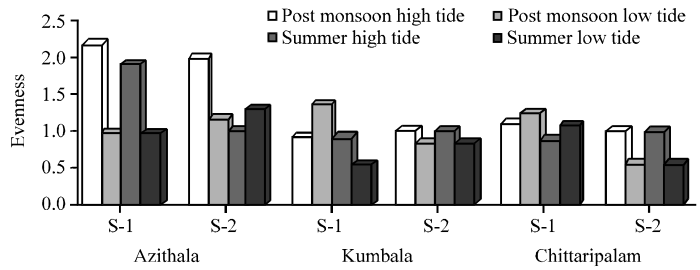


Fig. 10: Seasonal variations of zooplankton evenness recorded from different Estuarine

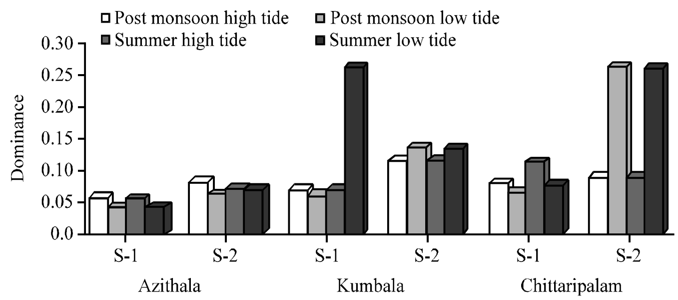


Fig. 11: Seasonal variations of zooplankton dominance recorded from different Estuarine

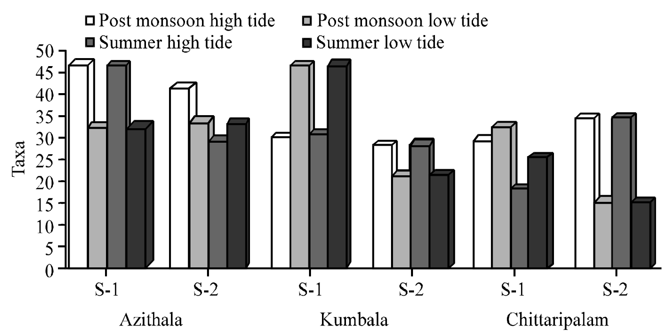


Fig. 12: Seasonal variations of zooplankton taxa recorded from different Estuarine

Station association: Dendrogram of station association reveal that all six stations. Azhithala station 1 and Chittari palam station 1 has the shortest distance linkage this close similarity between stations also point up the species composition. Its point out for occurrence, the composition of the zooplankton species is greatly comparable these stations. Similarly, Azhithala station 2 and Kumbala station 2 form second shortest distance (Fig. 13). From the CA the station Kumbala station 1 variation with other stations it's indicating the distribution of zooplankton highly variable from other station.

Scores plot of PC1 and PC2 displays the similarities of various zooplankton groups in Estuarine depicts the score plot of the first two PCs which represents the zooplankton group's correlation with each other. The zooplankton species such as 7 (Chaetognatha), (1) Foraminifera and (21) Fish eggs are negatively correlating with each other it indicates dissimilarity of zooplankton species distribution. The zooplankton groups; harpacticoida (13) and cyclopodia (14) are positively correlating with each other indicates that the zooplankton species such as *Euterfina acutifrons*, *Corycaeus speciosus*, *Oithona rigida* and *Oithona similis* are similar with observe to their family

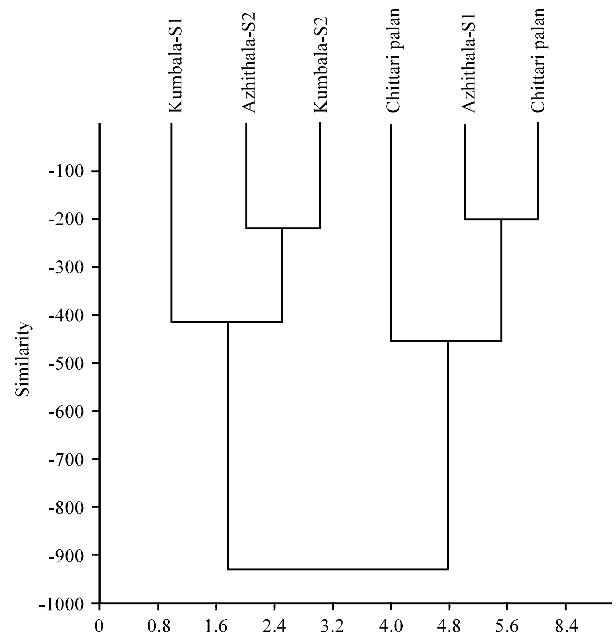


Fig. 13: Dendrogram of station associations showing the degree of similarity in zooplankton groups between stations

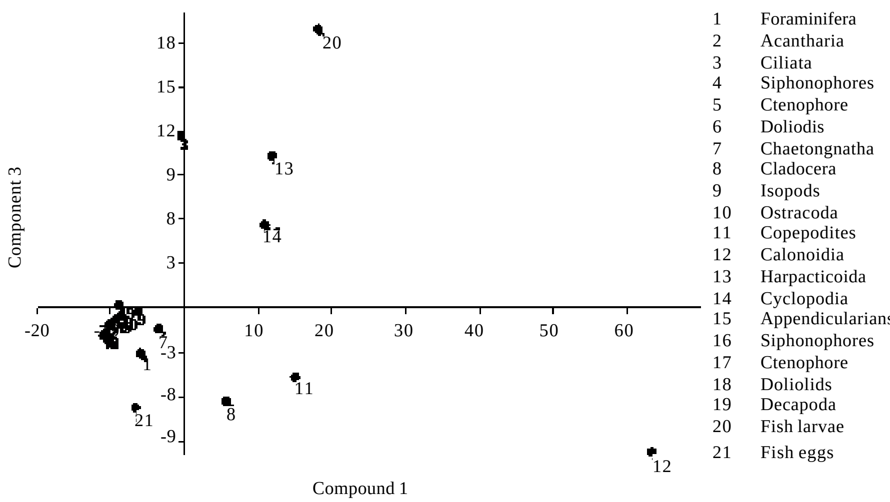


Fig. 14: Scores plot of PC1 and PC2 displays the similarities of various zooplankton groups in Estuarine region of Northern Kerala with respects to zooplankton abundance

member abundance at all station. From this plot it was observed that zooplankton groups such as (20) Fish Larvae, (12) Calonoidia, (8) Cladocera and (11) Copepodites are differing from all other groups (Fig. 14).

DISCUSSION

Zooplanktons which are everywhere in distribution form a vital link for turnover of organic matter and transfer from primary producers like diatoms to secondary consumers like fishes. The rate of zooplankton production can be used as a device to estimation the exploitable fish stock of an region (Tiwari and Nair, 1991). Zooplankton provides an important food source for larval fish and shrimp in natural waters and in aquaculture ponds. The high rate of zooplankton productions influences enrichment of organic matter and plays a vital role in secondary and tertiary productions, represented by young instars of fishes. The survival of the young of herbivorous finfish and shellfishes may depend on the availability of abundant littoral zooplankton and benthos (Manoharan *et al*., 2011). Meroplanktonic larvae prey on zooplankton and occasionally phtoplankton. Several families of finfish and shellfishes consume zooplankton wholly or partly in various stages of their life histories. Several authors are reported that in many country the failure of fishery was attributed to the reduced zooplankton especially copepod population (Stottrup, 2000).

Generally, surface water temperature is influenced by the intensity of solar radiation, evaporation, freshwater influx and cooling and mix up with ebb and flow from adjoining neritic waters. The recorded low water temperature during post monsoon 2013 might be due to strong land sea breeze and precipitation as agreed by Kalidasan (1991). Report provides an ample evidence for our view that the reduction in water temperature is mainly based on the intensity of the low air temperature and the recorded high value during summer, 2014 could be attributed to high solar radiation (Santhanam and Perumal, 2003). Statistical analysis showed a positive correlation ($r = 0.672$ during low tide) between air and surface water temperature for all the stations. Similarly high positive correlation was observed ($r = 0.811$ during high tide) between the air temperature and species diversity (Table 4 and 5).

The salinity acts as a limiting factor in the distribution of living organisms and its variation caused by dilution and evaporation is most likely to influence the fauna (Gibson, 1982). Generally, changes in the salinity in the brackish water habitats such as estuaries, backwaters and mangrove are due to the influx of freshwater from land run off, caused by monsoon or by tidal variations. Salinity showed a significant positive correlation with temperature. In the present study, salinity at all the stations was high during summer season and low during the post monsoon season. Higher values during summer could be attributed to the low amount of rainfall, higher rate of evaporation and also due to neritic water dominance in the Estuarine area (Gowda *et al*., 2001). Statistical analysis showed a positive correlation ($r = 0.889$ during high tide) between salinity and zooplankton evenness. Whereas negative correlation ($r = -0.76$ during high tide) between salinity and zooplankton dominance.

Hydrogen ion concentration (pH) in surface waters remained alkaline throughout the study period at all the stations with maximum value during the summer seasons and minimum values during post monsoon. Generally, fluctuations in pH values during different seasons of the year is attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, low primary productivity, reduction of salinity and temperature and decomposition of organic materials as stated by Karuppasamy and Perumal (2000) and Rajasegar (2003). High pH was recorded during summer seasons which might be due to the influence of seawater penetration and high biological activity (Das *et al*., 1997). The statistical analysis also revealed that pH showed high significant positive correlation ($r = 0.936$) with dissolved oxygen (Table 4 and 5). Negative correlation ($r = -0.921$) with evenness.

Variation in dissolved oxygen content was from 4.02-6.01 mL L^{-1} and from 4.02-6.20 mL L^{-1} during low and high tides, respectively. It is well known that, the temperature and salinity affect the dissolution of oxygen as stated by Vijayakumar *et al*. (2000). In the present investigation, a higher value of dissolved oxygen was recorded during post monsoon during low and high tide at

Table 4: Simple linear correlation coefficient (r) values for the physicochemical and biological parameters during low tide

Parameters	Den PM	Den SU	Div PM	Div SU	Ev PM	Ev SU	Dm PM	Dm SU	Tx PM	Tx SU	Dep PM	Dep SU	AT PM	AT SU	WT PM	WT SU	Sl PM	Sl SU	Ph PM	ph SU	DO PM	DO SU
Den PM	0.000	0.135	0.331	0.422	0.338	0.527	0.712	0.268	0.168	0.082	0.989	0.520	0.860	0.034	0.583	0.981	0.984	0.887	0.368	0.906	0.582	0.811
Den SU	0.683	0.000	0.603	0.065	0.625	0.114	0.250	0.016	0.946	0.815	0.450	0.610	0.893	0.433	0.380	0.431	0.748	0.569	0.191	0.273	0.122	0.733
Div PM	0.484	-0.270	0.000	0.528	504	0.501	0.010	0.571	0.002	0.019	0.155	0.768	0.816	0.125	0.068	0.518	0.517	0.369	0.918	0.384	0.430	0.449
Div SU	-0.410	-0.780	0.327	0.000	0.584	103	0.199	0.002	0.840	0.943	0.774	0.875	0.793	0.635	0.197	0.520	0.761	0.727	0.195	0.025	0.566	0.511
Ev PM	0.477	-0.260	0.982	0.285	0.00	0.509	0.031	0.649	0.007	0.044	0.209	0.723	0.602	0.184	0.064	0.732	0.714	0.573	0.856	0.526	0.520	0.391
Ev SU	-0.330	-0.710	0.347	0.974	0.341	0.00	0.240	0.015	0.820	0.950	0.921	0.818	0.507	0.613	0.144	0.768	0.995	0.995	0.400	0.058	0.768	0.493
Dm PM	-0.190	0.557	-0.920	-0.610	-0.85	-0.57	0.000	0.189	0.049	0.088	0.144	0.844	0.884	0.307	0.052	0.224	0.362	0.185	0.391	0.114	0.206	0.611
Dm SU	0.541	0.894	-0.290	-0.970	-0.24	-0.9	0.620	0.000	0.894	0.982	0.610	0.959	0.945	0.575	0.275	0.362	0.626	0.534	0.097	0.042	0.322	0.706
Tx PM	0.643	-0.040	0.962	0.107	0.932	0.121	-0.810	-0.070	0.000	0.002	0.135	0.724	0.915	0.029	0.192	0.568	0.401	0.326	0.939	0.559	0.577	0.466
Tx SU	0.756	0.124	0.886	0.038	0.824	0.034	-0.750	0.012	0.965	0.000	0.225	0.973	0.882	0.005	0.256	0.451	0.35	0.252	0.976	0.499	0.678	0.620
Dep PM	0.007	-0.390	0.658	0.152	0.599	0.053	-0.670	-0.270	0.682	0.583	0.000	0.095	0.690	0.310	0.776	0.473	0.059	0.135	0.569	0.724	0.257	0.460
Dep SU	-0.330	-0.270	0.156	-0.080	0.187	-0.12	-0.100	-0.030	0.186	0.018	0.736	0.000	0.793	0.979	0.531	0.656	0.327	0.813	0.879	0.536	0.755	0.645
AT PM	-0.090	-0.070	-0.120	-0.140	-0.27	-0.34	-0.080	-0.040	-0.060	0.079	0.210	-0.140	0.000	0.728	0.672	0.044	0.322	0.064	0.138	0.734	0.202	0.669
AT SU	-0.850	-0.400	-0.700	0.249	-0.63	0.264	0.505	-0.290	-0.860	-0.940	-0.500	-0.010	-0.180	0.000	0.598	0.547	0.321	0.278	0.866	0.802	0.895	0.673
WT PM	-0.290	0.443	-0.780	-0.610	-0.79	-0.67	0.807	0.534	-0.620	-0.550	-0.150	0.324	0.222	0.275	0.000	0.514	0.802	0.746	0.780	0.170	0.477	0.668
WT SU	0.013	0.401	-0.330	-0.330	-0.18	-0.16	0.584	0.457	-0.300	-0.390	-0.370	0.233	-0.820	0.312	0.337	0.000	0.287	0.014	0.038	0.175	0.065	0.668
Sl PM	-0.010	-0.170	0.334	0.161	0.193	-0	-0.460	-0.260	0.425	0.468	0.795	0.487	0.492	-0.490	0.133	-0.520	0.000	0.050	0.235	0.476	0.506	0.851
Sl SU	0.075	0.765	0.452	0.184	0.293	-0	-0.620	-0.320	0.488	0.556	0.683	0.125	0.785	-0.530	-0.170	-0.900	0.811	0.000	0.096	0.317	0.104	0.634
Ph PM	0.452	0.618	-0.050	-0.610	0.097	-0.43	0.433	0.734	0.041	-0.020	-0.300	0.081	-0.680	-0.090	0.147	0.836	-0.570	-0.740	0.000	0.090	0.178	0.754
ph SU	0.063	0.536	-0.440	-0.870	-0.33	-0.8	0.710	0.828	-0.300	-0.350	-0.190	0.321	-0.180	0.133	0.641	0.636	-0.370	-0.500	0.743	0.000	0.510	0.493
DO PM	-0.290	-0.700	0.401	0.298	0.333	0.156	-0.600	-0.490	0.290	0.218	0.551	0.165	0.606	-0.070	-0.360	-0.780	0.343	0.723	-0.630	-0.340	0.000	0.164
DO SU	0.126	-0.180	0.387	-0.340	0.433	-0.35	-0.270	0.198	0.373	0.259	0.378	0.242	0.224	-0.220	-0.230	-0.230	-0.100	0.249	0.165	0.353	0.648	0.000

Table 5: Simple correlation coefficient (r) values for the physicochemical and biological parameters during high tide

Parameters	Den PM	Den S	Diver PM	Diver-SU	EV PM	EV-SU	DOM PM	DOM-SU	TAXA PM	TAXA-SU	DEP PM
Den PM	0.000	0.580	0.532	0.923	0.418	0.998	0.715	0.962	0.785	0.786	0.794
Den S	0.288	0.000	0.557	0.815	0.575	0.792	0.604	0.738	0.654	0.697	0.443
DiverPM	0.323	-0.310	0.000	0.124	0.210	0.084	0.267	0.135	0.001	0.191	0.529
Diver-SU	-0.050	0.124	0.697	0.000	0.150	0.008	0.369	0.100	0.052	3E-04	0.633
EV PM	0.411	-0.290	**0.993**	0.665	0.000	0.089	0.295	0.169	0.005	0.236	0.506
EV-SU	-0.000	-0.140	0.752	0.927	0.745	0.000	0.273	0.192	0.053	0.029	0.323
DOM PM	0.192	0.271	-0.540	-0.450	-0.520	-0.540	0.000	0.060	0.203	0.38	0.030
DOM -SU	-0.030	-0.180	-0.680	-0.730	-0.640	-0.620	0.793	0.000	0.063	0.081	0.390
TAXA PM	0.144	-0.240	0.971	0.807	**0.942**	0.805	-0.610	-0.790	0.000	0.08	0.533
TAXA-SU	-0.140	0.205	0.618	**0.985**	0.572	0.859	-0.440	-0.760	0.760	0	0.724
DEP PM	-0.140	-0.390	0.325	0.250	0.343	0.491	-0.850	-0.430	0.323	0.186	0.000
DEP-SU	-0.670	-0.640	-0.020	-0.000	-0.050	0.202	-0.640	-0.100	0.038	-0.01	0.773
ATPM	-0.250	0.401	0.162	**0.811**	0.134	0.691	-0.090	-0.360	0.313	0.835	0.034
AT-SU	-0.190	-0.430	-0.280	-0.740	-0.300	-0.650	-0.210	0.187	-0.340	-0.71	0.202
WTPM	-0.740	0.008	0.040	0.633	-0.040	0.521	-0.140	-0.240	0.239	0.694	0.035
WT-SU	-0.050	0.327	-0.690	-0.770	-0.700	**-0.910**	0.223	0.267	-0.690	-0.67	-0.290
SL PM	-0.330	-0.100	0.586	0.874	0.545	0.889	-0.760	-0.760	0.717	0.866	0.628
SL-SU	0.161	0.666	-0.520	-0.130	-0.460	-0.140	0.021	0.050	-0.510	-0.11	0.208
PH PM	-0.630	0.226	-0.730	-0.450	-0.800	-0.670	0.310	0.278	-0.590	-0.3	-0.460
PH-SU	-0.510	-0.040	-0.670	-0.510	-0.670	-0.430	-0.240	0.190	-0.610	-0.45	0.425
DO PM	0.728	0.448	0.290	0.150	0.362	0.187	-0.360	-0.460	0.208	0.1	0.377
DO-SU	0.303	0.117	-0.200	-0.130	-0.110	0.100	-0.190	0.121	-0.290	-0.21	0.595

Parameters	DEP-SU	AT PM	AT-SU	WT PM	WT-SU	SL PM	SL-SU	PH PM	PH -SU	DO PM	DO-SU
Den PM	0.143	0.628	0.718	0.095	0.924	0.525	0.760	0.180	0.302	0.101	0.560
Den S	0.175	0.430	0.392	0.988	0.527	0.849	0.149	0.667	0.942	0.373	0.825
DiverPM	0.967	0.760	0.586	0.939	0.130	0.222	0.290	0.103	0.147	0.577	0.705
Diver-SU	0.998	0.050	0.096	0.177	0.072	0.023	0.807	0.374	0.305	0.777	0.803
EV PM	0.921	0.800	0.570	0.946	0.125	0.263	0.354	0.059	0.143	0.481	0.836
EV-SU	0.702	0.129	0.165	0.289	0.013	0.018	0.796	0.145	0.390	0.723	0.850
DOM PM	0.175	0.873	0.695	0.792	0.670	0.080	0.968	0.550	0.643	0.480	0.724
DOM -SU	0.852	0.478	0.723	0.652	0.609	0.078	0.926	0.594	0.718	0.358	0.819
TAXA PM	0.943	0.546	0.516	0.648	0.132	0.109	0.305	0.217	0.195	0.693	0.577
TAXA-SU	0.984	0.038	0.117	0.126	0.146	0.026	0.837	0.570	0.374	0.851	0.683
DEP PM	0.071	0.949	0.701	0.948	0.578	0.182	0.693	0.36	0.401	0.461	0.213
DEP-SU	0.000	0.923	0.390	0.548	0.834	0.357	0.924	0.919	0.165	0.623	0.637
ATPM	-0.050	0.000	0.027	0.049	0.224	0.136	0.659	0.833	0.641	0.947	0.980
AT-SU	0.434	**-0.860**	0.000	0.305	0.139	0.416	0.781	0.458	0.203	0.849	0.959
WTPM	0.312	0.813	-0.510	0.000	0.354	0.155	0.822	0.644	0.965	0.277	0.555
WT-SU	-0.110	-0.580	0.678	-0.460	0.000	0.157	0.538	0.113	0.223	0.934	0.950
SL PM	0.462	0.682	-0.410	0.658	-0.660	0.000	0.941	0.491	0.881	0.820	0.915
SL-SU	-0.050	0.232	-0.150	-0.120	0.319	-0.040	0.000	0.929	0.294	0.251	0.074
PH PM	0.054	-0.110	0.380	0.242	0.711	-0.350	0.047	0.000	0.314	0.252	0.385
PH-SU	0.647	-0.240	0.606	-0.020	0.585	-0.080	0.517	0.499	0.000	**0.936**	0.383
DO PM	-0.260	-0.040	-0.100	-0.530	0.044	0.121	0.557	-0.560	-0.040	0.000	0.205
DO-SU	0.247	0.013	-0.030	-0.310	-0.030	0.057	0.768	-0.440	0.440	0.603	0.000

all the stations. Higher dissolved oxygen concentration might be due to the cumulative effect of higher wind velocity joined with heavy rainfall and the resultant freshwater mixing

(Das *et al.*, 1997). Dissolved oxygen was observed low during summer which could be attriputed to high temperature and salinity of the water, i.e., oxygen holding capacity of water decrease with increasing temperature and salinity. The statistical analysis also revealed that DO showed high significant negative correlation (r = -0.78) with water temperature (Table 4 and 5). Positive correlation (r = 0.728) with density.

Totally 53 species of zooplankton were identified in the present investigation at Estuarine waters (Table 1). Of these, calonoidia (13), ciliate (8) and cyclopodia (6) other groups occurred less in small numbers. Several workers reported different copepods composition that including Santhanam *et al.* (1975) who reported 25 species of copepods from Porto Novo, 49 species of copepod were recorded in the Cochin water by Madhupratap and Haridas (1975), 34 species of copepods were recorded in the Gulf of Mannar by Maruthanayagam and Subramanian (1999), 33 species of copepods were recorded in the Gulf of Kachchh, Gujarat coast by Saravanakumar *et al.* (2007) and Sharma and Cyril (2007) were recorded 35 species from Kollam coast and Robin *et al.* (2009) observed total of 120 species of zooplankton.

From all the studied sites, it was inferred that among all zooplankton copepods has highest percentage composition. Similar observation was made earlier in other regions such as Lakshadweep Island (Achuthankutty *et al.*, 1989), Straits of Malacca (Rezai *et al.*, 2004), Palk Strait (Jayasiri, 2007), Gulf of Thailand (Maiphae and Sa-Ardrit, 2011) and Bay of Bengal (Santhanam *et al.*, 2012). Among various zooplankton species, *Paracalanus parvus*, *Acartia spinicauda*, *A. danae*, *A. centrura*, *Nanocalanus minor*, *Acrocalanus gracilis*, *A. gibber* and *Oithona rigida* which are present throughout the year with appreciable numbers during low and high tide at all stations.

The recorded high densities of zooplankton might be due to the relatively stable environmental condition which prevailed during those seasons and great neritic elements presence from the adjacent sea could have also contributed to the maximum density of zooplankton. Similar high summer population density of zooplankton was reported other regions by earlier workers (Karuppasamy and Perumal, 2000; Perumal *et al.*, 2008). Further, salinity is the key factor influencing the distribution and abundance of zooplankton (Goswami and Padmavati, 1996). The salinity showed positive correlation with zooplankton density (r = 0.765 during low tide, r = 0.666 during high tide). The recorded low population density during the postmonsoon due to the heavy input of freshwater as reported earlier by Goswami (1982). The recorded low post monsoonal density could be due to the hydrographically washable environmental condition. Goswami and Padmavati (1996) have stated that, the heavy flood changed the salinity, temperature and other environmental variables which inturn decreased the zooplankton density.

The recorded high summer species diversity values may be due to the high zooplankton density that also indicated the stable high salinity values. The similar findings were observed by Madhupratap *et al.* (1981) from Andaman Sea. The low species diversity was observed post monsoon season which could be attributed to heavy freshwater influx and low salinity (Godhantaraman, 1994). The turbidity during this season may also responsible for lower values. In the present observation, the species diversity was higher in station 1 than the station 2 it may be due to the presence of more neritic forms. Especially, the salinity plays an important role in higher diversity recorded at station 1. The species diversity showed positive correlation with zooplankton evenness (r = 0.982 during low tide, r = 0.993 during high tide).

Maximum evenness was recorded during the postmonsoon season and low evenness was observed summer season due to the unequal distribution of the species in these months and the high evenness values were obtained during post monsoon season both low and high tide in all the stations indicated that the species were equally distributed (Karuppasamy and Perumal, 2000). The statistical correlation values of evenness showed positive correlation (r = 0.982 during low tide, r = 0.927 during high tide) with species diversity at all the stations (Table 4 and 5). Zooplankton taxa in Estuarine ranged from 15 to 46. The statistical correlation values of zooplankton taxa showed positive correlation (r = 0.942 during low tide, r = 0.932 during high tide) with species evenness at all the stations (Table 4 and 5).

The observed low zooplankton productivity during monsoon might be due to the non-availability of food, low temperature and low salinity (Perumal *et al.*, 2009). In the present investigation, the increase or decrease of salinity in the water column exerts either a direct or an indirect effect in the appearance or disappearance of some forms and replacement by others. The study revealed that, the distribution of zooplankton reflects the status of Estuarine ecosystems diversity and productivity as a whole. The abundance and composition analysis of zooplankton from study area indicated that the areas are productive with high degree of diversity. Further, continuous zooplankton monitoring of the Estuarine would help coastal area management. Additional seasonal investigations from left over Estuarine are necessary for accurate biodiversity of zooplanktons in Estuarine regions of Northern Kerala.

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