



Research article

Seasonal variations and diversity of zooplankton in Karkala, Udupi, India

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Abstract

A detailed study was carried out in Anekere and Sigadikere lake of Udupi district, Karnataka, South India on physico-chemical parameters, and zooplankton composition during August 2007 to March 2008. In the present attempt, freshwater zooplankton groups like Radiolarians, Rotifers, Thecate hydroids, Scyphozoans, Cladocerans, Ostracods, Copepods, Mysids, Decapods, Gastropods and other groups were reported. One way ANOVA showed that there was no statistically significant difference ($p < 0.05$) in variation of within abiotic and biotic parameters in Anekere Lake. Whereas there was a significance of water temperature in Sigadikere during the study period. Cladocerans were the dominant zooplankton group at Anekere Lake. Cladocerans showed dominance both in number and diversity, followed by Copepods and Rotifers. This study also reveals that different groups of zooplankton have their own peak periods of density, which is affected by local environmental conditions. Dendrogram indicated that relationships between abiotic and biotic parameters in both the sites. Our study would form a useful tool for ecological monitoring and assessment at Anekere Lake.

Keywords: Anakere Lake, Diversity indices, Seasonal variation, Zooplankton

Introduction

The word plankton comes from the Greek word “plankton” which means “drifting”. Plankton are microscopic organism that float or drift with aquatic currents freely and in other bodies of water. A single organism in the plankton is called as plankter (Davis, 1955). Planktonic plants are called phytoplankton. The phytoplankton proper consist of chlorophyll-bearing plants, which are therefore capable of performing photosynthesis, whereas the saproplankton consist of no photosynthetic plants including fungi and bacteria. Zooplankton consist of those plankters, with a holozoic nutrition and thus include all of the planktonic animals. Zooplankton can be classified into 3 classes depending upon their size. Microzooplankton are usually <200 microns in size. Mesozooplankton are between 200 microns to 2 millimeters in size. Macrozooplankton (amphipods, shrimps, fish larvae and gelatinous

zooplanktons or jelly fishes is greater than 2 millimeters in size. Holozooplankton are those organisms which are planktonic throughout their whole life histories and meroplankton the developmental stages (mainly eggs and larvae) (Newell and Newell, 1977).

Zooplankton are primary consumers and capable of accumulating heavy metals in water. These metals may be passed through different trophic levels in aquatic food chain. Thus, it is necessary to understand whether the mortality is due to biomagnifications of heavy metals or pollutants. The fishery potential is fully related to the presence of zooplankton (Verma et al. 2013). Zooplankton forms a major link in the energy transfer at secondary level in aquatic food webs between autotrophs and heterotrophs.

Ayyappan and Gupta (1980) observed seasonal and spatial distribution of zooplanktons in the perennial tank located in Dakshina Kannada, Karnataka. Indur et al.

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(2015) studied on zooplankton diversity in freshwater reservoir of Yadigir district, Karnataka. Karkala's most fascinating wetland, Anekere, is a man-made wetland built by the ruler of Karkala Pandya Deva belong to Bhairarasa Dynasty. It has an area of 25 acres surrounded by bush vegetation consisting mainly of paddy fields and orchards of coconut and arecanut. This scenic pond was once the most productive ecosystem, which has lost now its past glory and become one of the most threatened wetland habitats in Karkala (Achar, 1996). Zooplankton have been long used as bioindicators of the eutrophication (Contreras et al. 2009). Therefore, the present study was taken up to know the status of zooplankton in Anekere lake, Karnataka, India.

Materials and Methods

The present study was carried out from two sites, 1. Anekere (13°12'24" N, 74°59'47"E) and 2. Sigadikere (13°12'18" N, 74°59'47" E), located in Karkala Taluk (Udupi district), Karnataka, South India. The study period was from August 2007 to March 2008. The samples were collected between 7–10 am. Air and water temperatures were measured with the help of a simple mercury thermometer. pH, salinity, dissolved oxygen and dissolved carbon dioxide were analyzed following APHA (1998).

The qualitative and quantitative analyses of zooplankton were done using Sedgwick-Rafter cell (for standardization) and Lackey's drop method. Six strips were counted in Sedgwick-Rafter cell with dimensions of 50 mm X 20mm X 1mm. In Lackey's drop method, the cover slip was placed over a drop of water on the slide and the whole of the cover slip was examined by parallel overlapping strips to count all the organisms in the drop. About 20 strips were examined in each drop. Number of sub-samples to be taken was dependent on the examining 2 to 3 successive sub-samples without any addition of unencountered species when compared to the already examined subsamples in the same sample. The species belonging to each group were noted down and the number of individuals in each species was counted. In addition to this, only dinoflagellates were examined in the present study. The number of organisms was expressed in total organisms per liter using the formula, *i.e.*, number of zooplankton "n" = P x C x 100/L, where P = number of plankton counted, C = volume of the sample collected and L = volume of water filtered.

Results and Discussion

Table 1: gives the results based on environmental parameters of freshwater obtained from different two sampling sites (Anekere and Sigadikere). Lowest (23.9°C: Site 1; 24.3°C: Site 2) and highest (27.5°C: Site 1; 27.9°C: Site 2) air temperatures were recorded in August (monsoon) and March (pre monsoon) respectively. Similarly, the lowest (20.5°C) and highest (23.7°C) water temperatures were recorded in August

(monsoon) and March (pre monsoon) in Site 1. Whereas in Site 2, the highest water temperature was found during January (last month of post monsoon) when the lowest water temperature 21.2°C was recorded in August (monsoon). The pH of water ranged from 6.0 (November) to 6.4 (January) in Site 1. At Site 1, the salinity ranged from 3.35 (December) to 4.46 (March). But at Site 2, the salinity varied from 2.54 (September) to 5.03 ppt (March). At both the sites, the highest value of salinity was recorded in March. The highest value occurred in Site 1 and Site 2 may be due to slightly lower water temperature (Jalilzadeh et al. 2008). The same lowest (monsoon) and highest (post and pre-monsoon) values of site 2 were observed in the present study. Salinity was high in March (pre-monsoon) in both the sites. It was found to be low in the post monsoon (December) and monsoon (September) in Site 1 and Site 2 respectively. The lowest DO value were noticed during the post monsoon season in both the sites. Perhaps the fluctuation of DO recorded in the present study is might be due to rainfall. The recorded dissolved CO₂ was ranged from 3.1 to 8.2 (mg/l) in Site 1, whereas it varied from 2.8 to 6.9 (mg/l) in Site 2. When the highest dissolved CO₂ was found the lower DO was occurred. The DO values reported from Unkal lake (Karnataka) are within our DO range (Ansari et al. 2008). The high pH of Site 2 may be attributed to the presence of algal blooms, which use CO₂ for photosynthesis and increase the pH of freshwater bodies. High CO₂ occurred in study areas may be due to the presence of large number of Cladocerans, Rotifers and Cyclopoidea (Jalilzadeh et al. 2008).

Table 1. Environmental parameters of freshwater obtained from two different sites

Site 1 (Anekere)						
Environmental parameters						
Month	AT (°C)	WT (°C)	pH	SAL (ppt)	DO (mg/l)	CO ₂ (mg/l)
Aug 07	23.9	21.2	6.1	3.40	7.1	3.1
Sep	26.3	23.4	6.2	3.76	6.3	5.0
Oct	25.0	23.0	6.2	3.39	5.9	3.3
Nov	26.0	21.5	6.0	3.46	6.1	5.9
Dec	26.8	22.0	6.2	3.35	5.2	8.2
Jan 08	27.3	23.5	6.4	3.44	7.5	6.3
Feb	26.9	22.0	6.2	3.39	7.3	5.6
Mar	27.5	23.2	6.3	4.46	7.2	6.2

Site 2 (Sigadikere)						
Environmental parameters						
Month	AT (°C)	WT (°C)	pH	SAL (ppt)	DO (mg/l)	CO ₂ (mg/l)
Aug 07	24.3	20.5	6.3	3.32	6.5	2.8
Sep	27.2	22.0	6.0	2.54	7.0	4.6
Oct	24.8	21.0	6.1	2.94	8.2	4.5
Nov	26.0	21.5	6.4	3.72	5.4	4.9
Dec	26.3	21.3	6.4	3.94	6.4	4.9
Jan 08	27.0	22.4	6.2	3.72	7.9	6.9
Feb	26.9	23.1	6.5	3.90	7.1	5.7
Mar	27.9	23.7	6.4	5.03	7.5	6.0

Zooplankton take an important role in freshwater aquatic ecosystems. The diversity of zooplankton correlated with various (physico-chemical and biological factors) (Khan et al. 2016). In recent years, several studies were carried out in various parts of Karnataka to understand the distribution and diversity of freshwater zooplankton. The percentage composition of zooplankton at the two study sites based on the quantitative analyses during the period of study are shown in (Table 2&3). The maximum and minimum density at Site 1 occurred in the groups of Cladocerans (97.6%) and others (2.4%) respectively in the same month of March. At Site 2, the maximum

density of zooplankton was found in the groups of Copepods (50.0%) and Ostracods (50.0%) in August and January respectively. Whereas the minimum density in Rotifers, Dinoflagellates-Cladocerans, Thecate hydroids-Copepods-Ostracods and Copepods was found in August, September, November and December respectively. Similar result was also recorded by Rajashekhar et al. (2010) on the seasonal variations of physico-chemical parameters and zooplankton of reservoir of Gulbarga district (Karnataka). They postulated that the low diversity and abundance of ostracoda group recorded may be due to soft nature of water.

Table 2. Different groups of zooplankton in Site 1

Percentage distribution of zooplankton in Site 1								
Order	August 07	September	October	November	December	January	February	March 08
Dinoflagellates	75.0	-	-	-	-	-	-	-
Radiolarians	-	-	-	-	66.7	-	-	-
Rotifers	-	-	28.6	-	-	-	-	-
Thecate Hydroids	-	-	-	33.3	-	-	-	-
Scyphozoans	-	-	-	-	-	60.0	-	-
Copepods	-	50.0	28.6	50.0	-	-	34.1	-
Cladocerans	-	33.3	28.6	-	-	40.0	-	97.6
Ostracods	-	-	14.3	16.7	-	-	-	-
Mysids	-	-	-	-	33.3	-	-	-
Decapods	25.0	-	-	-	-	-	-	-
Gastropods	-	-	-	-	-	-	64.2	-
Others	-	16.7	-	-	-	-	3.2	2.4
Total	100	100	100	100	100	100	100	100

Table 3. Different groups of zooplankton in Site 2

Percentage distribution of zooplankton in Site 2								
Order	August 07	September	October	November	December	January	February	March 08
Dinoflagellates	-	20.0	-	-	21.7	37.5	-	-
Tintinnids	-	60.0	30.8	-	-	-	-	-
Rotifers	12.5	-	-	-	26.1	25.0	-	-
Thecate Hydroids	37.5	-	-	12.5	-	-	-	-
Cladocerans	-	20.0	30.8	-	-	37.5	25.0	50.0
Copepods	50.0	-	-	12.5	13.0	-	-	50.0
Ostracods	-	-	38.5	12.5	39.1	-	50.0	-
Decapods	-	-	-	37.5	-	-	25.0	-
Others	-	-	-	25.0	-	-	-	-
Total	100	100	100	100	100	100	100	100

From Table 4, in Site 1 AT was positively correlated with CO₂ and negatively correlated with Dinoflagellates and Decapods. pH was positively correlated with WT, it was strongly correlated with Cladocerans. Similarly, salinity was also positively correlated with Cladocerans. Mysids

was strongly positively correlated with Radiolarians. Decapods showed a negative correlation with AT, but it had a strong positive correlation with Dinoflagellates. In case of Site 2 (Table 5), AT had positive correlation with WT and CO₂. WT showed similar positive significance

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value with abiotic variable, CO₂ and biotic group commonly known as water fleas (Singh et al. 2002).
(cladocerans). Cladocerans are the small crustaceans About 620 species were identified so far, with many more

Table 4. Correlation matrix of abiotic and biotic parameters of Site 1

	AT	WT	pH	SAL	DO	CO ₂	DF	RL	RT	TH	SZ	CP	CR	OC	MS	DP	GP	Others
AT	1																	
WT	0.520	1																
pH	0.604	0.792*	1															
SAL	0.433	0.463	0.323	1														
DO	0.180	0.171	0.421	0.292	1													
CO ₂	0.802*	0.098	0.274	0.128	-0.229	1												
DF	-0.762*	-0.569	-0.338	-0.194	0.252	-0.570	1											
RL	0.194	-0.212	0.000	-0.247	-0.674	0.666	-0.143	1										
RT	-0.399	0.234	0.000	-0.205	-0.352	-0.522	-0.143	-0.143	1									
TH	-0.070	-0.435	-0.676	-0.130	-0.221	0.119	-0.143	-0.143	-0.143	1								
SZ	0.358	0.458	0.676	-0.151	0.467	0.208	-0.143	-0.143	-0.143	-0.143	1							
CP	-0.181	0.049	-0.529	-0.112	-0.364	-0.254	-0.335	-0.335	0.261	0.559	-0.335	1						
CR	0.449	0.877**	0.748*	0.726*	0.364	0.017	-0.348	-0.348	0.158	-0.348	0.411	-0.157	1					
OC	-0.359	-0.153	-0.516	-0.255	-0.438	-0.308	-0.218	-0.218	0.655	0.655	-0.218	0.626	-0.145	1				
MS	0.194	-0.212	0.000	-0.247	-0.674	0.666	-0.143	1.000**	-0.143	-0.143	-0.143	-0.335	-0.348	-0.218	1			
DP	-0.762*	-0.569	-0.338	-0.194	0.252	-0.570	1.000**	-0.143	-0.143	-0.143	-0.143	-0.335	-0.348	-0.218	-0.143	1		
GP	0.227	-0.212	0.000	-0.205	0.355	0.027	-0.143	-0.143	-0.143	-0.143	-0.143	-0.037	-0.348	-0.218	-0.143	-0.143	1	
Others	0.100	0.430	0.035	0.267	-0.058	-0.086	-0.178	-0.178	-0.178	-0.178	-0.178	0.532	0.188	-0.271	-0.178	-0.178	-0.041	1

*. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed), Dinoflagellates = DF, Radiolarians = RL, Rotifers = RT, Thecate hydroids = TH, Scyphozoans = SZ, Copepods = CP, Cladocerans = CR, Ostracods = OC, Mysids = MS, Decapods = DP, Gastropods = GP.

Table 5. Correlation matrix of abiotic and biotic parameters of Site 2

	AT	WT	pH	SAL	DO	CO ₂	DF	TN	RT	TH	CP	CR	OC	DP	Others
AT	1														
WT	0.892**	1													
pH	0.141	0.324	1												
SAL	0.485	0.637	0.765*	1											
DO	0.160	0.316	-0.436	-0.029	1										
CO ₂	0.777*	0.771*	0.172	0.499	0.405	1									
DF	0.312	0.046	-0.268	-0.060	0.241	0.524	1								
TN	-0.029	-0.187	-0.862**	-0.756*	0.313	-0.236	-0.058	1							
RT	-0.076	-0.257	0.056	0.093	0.015	0.167	0.807*	-0.410	1						
TH	-0.685	-0.586	0.116	-0.157	-0.463	-0.0758*	-0.338	-0.281	0.073	1					
CP	-0.262	-0.131	0.326	0.404	-0.271	-0.484	-0.387	-0.436	0.038	0.732*	1				
CR	0.536	0.728*	-0.103	0.359	0.836**	0.745*	0.216	0.012	-0.105	-0.564	-0.238	1			
OC	-0.118	-0.004	0.423	0.033	-0.009	0.065	-0.192	-0.116	-0.054	-0.350	-0.443	-0.097	1		
DP	0.029	0.112	0.531	0.123	-0.611	0.082	-0.381	-0.316	-0.410	0.056	-0.203	-0.265	0.329	1	
Others	-0.099	-0.163	0.263	0.044	-0.710*	-0.053	-0.256	-0.213	-0.276	0.189	-0.033	-0.427	-0.078	0.808*	1

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed), Dinoflagellates = DF, Tintinnids = TN, Rotifers = RT, Thecate hydroids = TH, Copepods = CP, Cladocerans = CR, Ostracods = OC, Decapods = DP.

undisturbed. It is reported that the biomass and density of this group was primary determined by food supply (Singh et al. 2002). In our study, perhaps this group was abundant when the food supply (phytoplankton) was maximum (Shivashankar and Venkataramana, 2013). In contrast, Rotifers were reported as dominant during summer period, the cladoceran population

was moderate due to dense growth of rotifers and thus avoiding the temperature is the primary factor affecting the distribution and occurrence of cladocerans (Qadri and Yousof, 1980). When pH showed a positive correlation with salinity it showed a strong negative correlation with Tintinnids ($r = -0.862$).

Table 6. ANOVA on the abiotic and biotic between seasons (Site 1)

		Sum of Squares	df	Mean Square	F	Sig.
AT	Between Groups	4.441	2	2.221	1.824	0.254
	Within Groups	6.088	5	1.218		
WT	Between Groups	0.095	2	0.048	0.042	0.959
	Within Groups	5.640	5	1.128		
pH	Between Groups	0.010	2	0.005	0.278	0.768
	Within Groups	0.090	5	0.018		
SAL	Between Groups	0.354	2	0.177	1.371	0.335
	Within Groups	0.645	5	0.129		
DO	Between Groups	1.577	2	0.789	1.222	0.370
	Within Groups	3.225	5	0.645		
CO ₂	Between Groups	5.242	2	2.621	0.909	0.461
	Within Groups	14.420	5	2.884		
DF	Between Groups	12150	2	6075	1.875	0.247
	Within Groups	16200	5	3240		
RL	Between Groups	7200	2	3600	0.417	0.680
	Within Groups	43200	5	8640		
RT	Between Groups	1800	2	900	0.417	0.680
	Within Groups	10800	5	2160		
TH	Between Groups	1800	2	900	0.417	0.680
	Within Groups	10800	5	2160		
SZ	Between Groups	1800	2	900	0.417	0.680
	Within Groups	10800	5	2160		
CP	Between Groups	4050	2	2025	0.239	0.796
	Within Groups	42300	5	8460		
CR	Between Groups	4050	2	2025	0.168	0.850
	Within Groups	60300	5	12060		
OC	Between Groups	1800	2	900	1.250	0.363
	Within Groups	3600	5	720		
MS	Between Groups	1800	2	900	0.417	0.680
	Within Groups	10800	5	2160		
DP	Between Groups	1350	2	675	1.875	0.247
	Within Groups	1800	5	360		
GP	Between Groups	5400	2	2700	1.875	0.247
	Within Groups	7200	5	1440		
Others	Between Groups	1218.375	2	609.188	1.692	0.275
	Within Groups	1800.500	5	360.100		

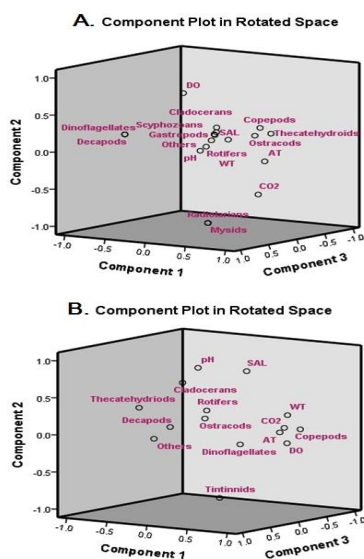


Fig. 1. Coordinate plots of abiotic and biotic parameters by plotting first three components (Site 1: Upper and Site 2: Lower)

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Table 7. ANOVA on the abiotic and biotic between seasons (Site 2)

		Sum of Squares	df	Mean Square	F	Sig.
AT	Between Groups	3.327	2	1.664	1.150	0.388
	Within Groups	7.232	5	1.446		
WT	Between Groups	5.824	2	2.912	6.079	0.046
	Within Groups	2.395	5	0.479		
pH	Between Groups	0.091	2	0.046	1.941	0.238
	Within Groups	0.118	5	0.024		
SAL	Between Groups	2.384	2	1.192	3.918	0.095
	Within Groups	1.521	5	0.304		
DO	Between Groups	0.329	2	0.165	0.154	0.861
	Within Groups	5.332	5	1.066		
CO ₂	Between Groups	5.244	2	2.622	2.540	0.173
	Within Groups	5.161	5	1.032		
DF	Between Groups	6950	2	3475	0.706	0.537
	Within Groups	24600	5	4920		
TN	Between Groups	8550	2	4275	0.792	0.503
	Within Groups	27000	5	5400		
RT	Between Groups	4950	2	2475	.764	0.513
	Within Groups	16200	5	3240		
TH	Between Groups	9900	2	4950	1.310	0.349
	Within Groups	18900	5	3780		
CP	Between Groups	12150	2	6075	0.625	0.572
	Within Groups	48600	5	9720		
CR	Between Groups	14850	2	7425	1.331	0.344
	Within Groups	27900	5	5580		
OC	Between Groups	17212.5	2	8606	0.873	0.473
	Within Groups	49275.0	5	9855		
DP	Between Groups	4050.0	2	2025	0.321	0.739
	Within Groups	31500.0	5	6300		
Others	Between Groups	1800.0	2	900	0.417	0.680
	Within Groups	10800.0	5	2160		

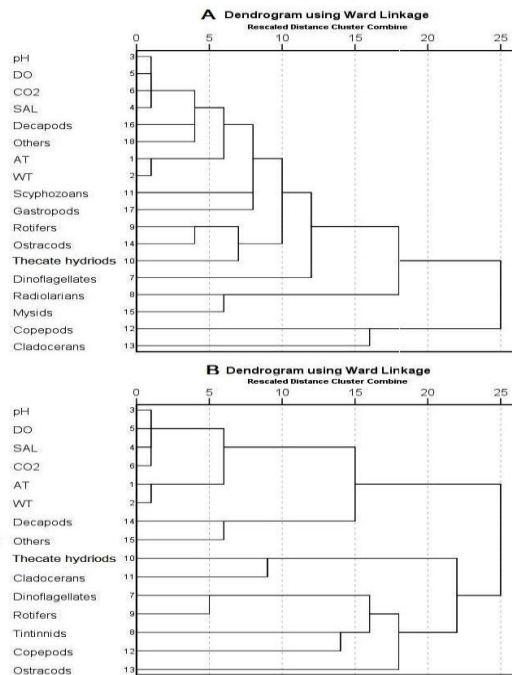


Fig. 2. Dendrogram showing relative similarities of sample groups produced by complete linkage agglomerative cluster analysis, at Site 1 (upper figure) and Site 2 (lower figure)

Table 8. Results of the Principal Component Analysis performed with the recorded abiotic and biotic variables from Site 1

Rotated Component Matrix						
Variables	Component					
	1	2	3	4	5	6
AT	0.845	-0.059	0.191	0.470	0.048	0.117
WT	0.623	0.259	0.524	-0.185	0.452	-0.102
pH	0.455	0.130	0.782	0.073	0.229	0.322
SAL	0.228	0.269	0.169	0.379	0.614	-0.272
DO	-0.078	0.787	0.321	0.419	-0.087	0.294
CO ₂	0.600	-0.565	-0.044	0.527	0.023	0.200
Dinoflagellates	-0.980	0.103	0.072	0.115	-0.004	0.085
Radiolarians	0.070	-0.982	0.095	0.112	-0.053	0.077
Rotifers	0.028	0.039	0.067	-0.973	0.050	0.005
Thecate hydroids	0.099	0.070	-0.985	0.074	0.029	0.075
Scyphozoans	0.292	0.254	0.287	0.079	0.144	0.673
Copepods	0.244	0.219	-0.584	-0.354	-0.040	-0.596
Cladocerans	0.418	0.389	0.436	-0.039	0.676	0.067
Ostracods	0.097	0.083	-0.701	-0.686	0.061	0.061
Mysids	0.070	-0.982	0.095	0.112	-0.053	0.077
Decapods	-0.980	0.103	0.072	0.115	-0.004	0.085
Gastropods	0.184	0.232	0.146	0.179	-0.890	-0.075
Others	0.175	0.155	0.183	0.121	0.136	-0.844
Eigen value	4.062	3.405	3.219	2.512	1.947	1.896
Variance (%)	22.567	18.919	17.883	13.955	10.817	10.532
Cumulative (%)	22.567	41.487	59.370	73.324	84.141	94.673

Extraction Method: Principal Component Analysis.
 Rotation Method: Varimax with Kaiser Normalization.

Table 9. Results of the Principal Component Analysis performed with the recorded abiotic and biotic variables from Site 2

Rotated Component Matrix					
Variables	Component				
	1	2	3	4	5
AT	0.908	0.084	0.047	0.059	-0.121
WT	0.900	0.295	-0.103	-0.213	-0.040
pH	0.066	0.906	0.297	-0.098	0.263
SAL	0.450	0.854	-0.020	-0.046	-0.101
DO	0.388	-0.241	-0.826	-0.013	0.090
CO ₂	0.916	0.136	-0.022	0.302	0.143
Dinoflagellates	0.295	-0.165	-0.125	0.929	-0.052
Tintinnids	-0.005	-0.926	-0.188	-0.245	-0.008
Rotifers	-0.164	0.238	-0.185	0.939	-0.007
Thecate hydriods	-0.788	0.257	0.127	-0.097	-0.436
Cladocerans	-0.435	0.591	-0.145	-0.221	-0.614
Copepods	0.762	0.028	-0.528	-0.084	-0.030
Ostracods	-0.053	0.168	0.004	-0.103	0.973
Decapods	0.099	0.189	0.840	-0.294	0.299
Others	-0.039	0.030	0.931	-0.123	-0.080
Eigen value	4.350	3.143	2.756	2.133	1.738
Variance (%)	28.953	20.953	18.375	14.222	11.587
Cumulative (%)	28.997	49.950	68.325	82.547	94.134

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

Table 10. Diversity indices for Site 1 and Site 2

Site 1				Site 2			
Month	Shannon	Simpson	Evenness	Month	Shannon	Simpson	Evenness
Aug 07	0.5623	0.6250	0.8113	Aug	1.0030	0.4063	0.9127
Sep	1.0110	0.3889	0.9206	Sep	0.6730	0.4400	0.9710
Oct	1.3520	0.2653	0.9751	Oct	1.0550	0.3373	0.9602
Nov	1.0110	0.3889	0.9206	Nov	0.5623	0.3333	0.8113
Dec	0.6365	0.5556	0.9183	Dec	1.5470	0.2854	0.9610
Jan 09	0.6730	0.5200	0.9710	Jan	1.2150	0.3438	0.8764
Feb	0.7724	0.5161	0.7031	Feb	1.2910	0.3750	0.9314
Mar	0.1147	0.9524	0.1654	Mar	0.6730	0.5000	0.9710
Aug	0.5623	0.6250	0.8113	Aug	0.0000	0.4063	****
Entire	2.1770	0.8511	0.8761	Entire	2.0910	0.8658	0.9518

*Result could not be generated due to the occurrence of one group during the study period.

Salinity was negatively correlated with Tintinnids. DO showed strongly positively correlated with Cladocerans, but negatively correlated with others. CO₂ was positively correlated with Thecate hydroids when it was positively correlated with Cladocerans (CR). Dinoflagellates had a positive correlation with Rotifers alone. There was a positive correlation between Copepods and Thecate hydroids. Decapods had a positive correlation with others.

One way ANOVA indicated that there was no statistically significant difference ($p < 0.05$) in variation of within abiotic and biotic parameters in Site 1. Whereas there was a sign of significance of water temperature (WT) in Site 2 during the study period (Table 6 and 7). From (Table 8 and 9) six and five components from PCA for Site 1 and Site 2 were extracted respectively. For the Site 1, PCA performed on environmental and biological parameters and the data revealed a total of six components, which accounted for a variance of 94.67%. Component 1 (AT, WT, CO₂, Dinoflagellates and Decapods) accounted for 22.57% of variance followed by Component 2 (DO, Radiolarians and Mysids) accounted for 19.92% of variance, Component 3 (pH and Thecate hydroids) accounted for 17.88% of variance. Component 4 (Rotifers and Ostracods), Component 5 (SAL, Cladocerans and Gastropods) and Component 6 (Scyphozoans, Copepods and Others) accounted for 13.967%, 10.82% and 10.53% of variance respectively of variance. In case of Site 2, the result from PCA was found a total of five components, which accounted for a variance of 94.09%. Component 1 (AT, WT, CO₂, Thecate hydroids and Copepods) accounted for 28.95% of variance followed by Component 2 (pH, salinity and Tintinnids) accounted for 20.95% of variance, Component 3 (DO, Decapods and Others) accounted for 18.38% of variance. Component 4 (Dinoflagellates and Rotifers) accounted for 14.22% and Component 5 (Cladocerans and Ostracods) accounted for 11.59% of variance respectively in the present study.

From (Table 10), the maximum values of Shannon, Simpson and Evenness indices at Site 1 were found to be 1.3520 (October), 0.9524 (March) and 0.9751 (October) respectively. Whereas the minimum values of

the above three indices were 0.1147 (March), 0.2653 (October) and 0.1654 (March) respectively. In case of Site 2, the maximum Shannon index (1.5470) was higher than that of Site 1. The maximum Simpson index (0.4400) was lower compared to Site 1. However, the Evenness index (0.9751) is comparable with that (0.9710) of Site 1. For the entire period, the Simpson index (2.1770) of Site 1 was higher than Site 2 (2.0910). But the Simpson (0.8658) and Evenness indices (0.9518) of Site 2 was lower than Site 1.

At Site 1, AT, WT and CO₂ show higher loadings with positive value in the first component except for dinoflagellates and decapods ($r = -0.980$) in Fig. 1A. Component 3 explain 17.88% of the total variance and carry higher positive and negative loadings of pH and Thecate hydroids respectively (Fig. 1A). At Site 2, AT, WT and CO₂ with copepods show higher positive loadings in the first component with a negative correlation of thecate hydroids ($r = -0.788$) (Fig. 1B). In the second component, higher positive loadings of abiotic variables, pH and salinity were observed, only biotic variable group, Tintinnids was found as the higher negative value ($r = -0.926$). Apart from this, Cluster analysis (dendrogram) showed relationships between abiotic and biotic parameters in the present study for Site 1 and 2 (Fig. 2A and 2B). On the other hand, the biotic parameters were influenced by the abiotic parameters at the both sites.

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