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Statistical approaches for computing diversity of zooplankton in the Andaman sea

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Abstract: Zooplankton is an economically and ecologically important group of aquatic animals and their ecological processes influence fishery, oceanography and climate. The present study attempts to analyse community structure and diversity of zooplankton in Andaman sea using various richness, diversity and evenness indices and similarity and resemblance functions. The results showed species richness indices (Margalef and Menhinick) hold good for zooplankton data. The evenness indices, chord distance and geodesic distance provided realistic values for analyzing zooplankton community structure hold good for a zooplankton data. Principal Component analysis being a multivariate eigen analysis provided a better understanding of community in zooplankton across sites and principal components.

Resumen: El zooplancton constituye un grupo de animales acuáticos con importancia ecológica y económica, y sus procesos ecológicos influyen sobre la pesquería, la oceanografía y el clima. El presente estudio persigue analizar la diversidad y la estructura de la comunidad de zooplancton en el mar de Andaman usando varios índices de riqueza, diversidad y equidad, así como funciones de similitud y de parecido. Los resultados muestran que los índices de riqueza de especies (Margalef y Menhinick) son adecuados para los datos de zooplancton. Los índices de equidad, la distancia de cuerda y la distancia geodésica proporcionaron valores realistas para analizar la estructura de la comunidad zooplantónica y también fueron adecuados para los datos de zooplancton. El análisis de componentes principales, al ser un análisis multivariable propio, proporcionó una mejor comprensión de los patrones presentes en las comunidades de zooplancton entre sitios y entre componentes principales.

Resumo: O zooplâncton constitui um grupo de animais aquáticos com elevada importância económica e ecológica, e os seus processos ecológicos influenciam as pescas, a oceanografia e o clima. Os estudos actuais tentam analisar a estrutura de comunidade e a diversidade do zooplancton no mar de Andaman, com recurso à análise de vários índices de riqueza, diversidade e de uniformidade, de funções de similaridade e semelhança. Os resultados mostraram que os índices de riqueza específica (Margalef e Menhinick) são consistentes para os dados do zooplancton. Os índices de uniformidade, distância da corda e distância geodésica proporcionam valores realistas para analisar a estrutura da comunidade do zooplâncton. A análise das componentes principais, sendo uma análise dos valores matriciais próprios, proporciona a melhor compreensão dos padrões de comunidade do zooplâncton através das estações e componentes principais.

Key words: Andaman sea, indices, principal component analysis, resemblance functions, zooplankton.

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Introduction

Zooplankton is economically and ecologically important group of aquatic organisms, that occupy a wide range of habitats extending from the pleuston to benthos. A large number of non-insect animal species live in the ocean and have planktonic life stages (Davis *et al.* 1996). Amongst them copepods, chaetognaths, amphipods, euphausiids, pteropods, heteropods, larval stages of meroplankton as well as holoplankton are major constituents of zooplankton community. Diversity indicates the degree of complexity of community structure. It is a function of number of species (richness) and the abundance (evenness). Diversity has often been related to environmental characteristics of water masses and the energy within the community (Omori & Ikeda 1984).

Ecological statistics includes numerous quantitative methodologies for analyzing the patterns in biotic communities. Several workers have used diversity indices, correlation matrix and analysis of variance (Gajbhiye *et al.* 1991; Goswami 1979; Goswami & Goswami 1990; Madhupratap & Haridas 1975; Nair, 1976; Madhupratap *et al.* 1981) for analyzing the structure of zooplankton community. The statistical methods can provide a better insight for understanding abundance, richness and patchiness of zooplankton in aquatic systems. Therefore, the present study was aimed at analyzing species diversity and community structure of zooplankton in the Andaman sea, using various statistical methods (species richness indices, resemblance functions, cluster analysis and principal component analysis).

Materials and methods

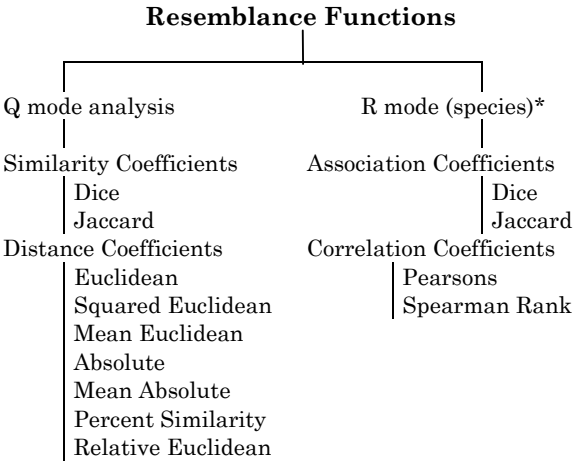
The zooplankton samples were collected at 28 stations at Andaman sea, using a Bongo net with a mesh size of 300 μm. A flow meter (T.S.K.) was attached to the mouth of the net to calculate the amount of water filtered through the net. Quantitative sampling was done from 200-0 meters water column. The samples were preserved in four percent formaldehyde solution for analyzing species composition and numerical abundance. Zooplankton abundance and species composition were analyzed using diversity indices, resemblance functions, cluster analysis and principal component analysis (PCA) using data from five representative sampling stations.

Richness indices are based on the relationship between 'S' (total number of species in a community) and the total number of individuals observed 'n', which increases with increasing sample size. Diversity numbers N0, N1 and N2 are the units of number of species called 'effective numbers' of species present in a sample, which is measure of the degree to which the proportional abundance are distributed among the species, where, N0 = number of all species in the samples irrespective of abundance, N1 = number of abundant species in a sample, N2 = number of very abundant species.

Resemblance functions as described by Sneath & Sokal (1973) were used to quantify the similarity or dissimilarity between species based on observations of the five sampling units - SU's and species abundance. Resemblance functions were represented as similarity coefficients and distance coefficients. The Q mode analysis (SU's) has been done following Ludwig & Reynolds (1988). Cluster analysis is a classification technique for placing similar entities or objects into groups or clusters in the form of dendrogram based similarity matrix method (simple linkage clustering) and the data have been analyzed by following Omori & Ikeda (1984).

The data on abundance of 19 commonly occurring epipelagic zooplankton species in five sampling units/stations (SU's) have been used to study the variances/co-variances/correlations among the zooplankton community by computing principal component factor analysis (Omori & Ikeda 1984).

The resemblance function for computing similarity and association coefficients can be summed up as follows:



Relative Absolute
Chord
Geodesic

Results and discussion

The richness values (R2) (Table 1) are high for sampling stations II and IV revealing that species richness is high at these particular stations. The richness values for zooplankton tend to show

Table 1. Zooplankton species composition, abundance, richness, diversity and evenness indices at five sampling stations in Andaman sea.

Zooplankton species	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Copepods					
Euchaeta marina	13	8	5	3	16
Oncaea venusta	75	78	78	10	22
Oncaea media	106	91	91	12	21
Sapphirina nigromaculata	6	2	8	2	91
Rhinocalanus nasutus	22	13	31	2	76
Undinula vulgaris	4	3	4		8
Eucalanus attenuatus	-	13			9
Corycaeus speciousus	2	4	61	6	58
Corycaeus affinis	24	18	58	8	26
Pleuromamma xiphias	6	13	4	7	9
Chaetognaths					
Sagitta robusta	27	4	18	6	13
Sagitta nagae	14	21	6		
Sagitta enflata	2	27	19	2	21
Sagitta serratodentata	4	17	25		
Pterosagitta draco	24	8	8		9
Siphonophores					
Praya reticulata	18	10	4	8	3
Chelophyes appendiculata	2		2	4	12
Diphyes dispar	4	4	6	3	14
Sulculeolaria biloba	3	2	9	2	9
Total number of species	18	18	18	14	17
Total no. of individuals	356	336	437	75	417
Richness indices					
Margalef (R1)	2.89	2.92	2.80	3.01	2.65
Menhinick (R2)	0.95	0.98	0.86	1.61	0.83
Simpson'd index	0.15	0.15	0.12	0.08	0.12
Hill's 1st diversity no. (N1)	7.53	8.00	8.41	9.97	9.39
Hill's 2nd diversity no. (N2)	0.31	7.14	8.33	12.50	9.09
Sheldon's index	1.22	1.28	1.45	1.67	1.70
Shannon - weiner index	1.97	1.92	2.08	2.51	2.36
Margalef's index	6.66	6.70	6.43	6.95	6.10
Pileou's evenness index (J')	0.77	0.78	0.81	0.93	0.85
Evenness indices					
E1 = Pileou's evenness	0.69	0.71	0.73	2.36	0.78
E2 = Sheldon's evenness	0.41	0.44	0.46	0.71	0.55
E3 = Heip's evenness	0.38	0.41	0.43	0.69	0.52
E4 = Hill's evenness	0.04	0.89	0.99	1.25	0.96
E5 = Modified Hill's ratio	0.10	0.87	0.98	1.28	0.96

higher values in night samples, also the R1 and R2 values do not show larger fluctuations as it is seen that, R1 ranges from 2.65 to 3.00 and R2 ranges from 0.83 to 1.60. The high R2 value for station number IV may be due to the time of sampling (22 hrs.). Species diversity indices for station I indicate a functional relationship existing between number of species and number of individuals in zooplankton community. Further, as R2 values do not show larger fluctuations the zooplankton communities are definitely comparable. Hence, it can be said that these two richness indices hold good for analyzing a zooplankton community structure.

The results for Effective Numbers of zooplankton - N1 and N2 (Table 1) were found to be higher for the sampling station IV indicating an increase in dominant species at station IV which confirms the observational data (Table 1) as well. Hence, these indices revealed a steady rise in the number of dominant species particularly at station IV. The diversity indices such as Sheldon's Index, Shannon - Weiner Index and Margalef's Index showed maximum values for station IV, again indicating the significance of the effective numbers.

From the rarefraction curves for Evenness indices (Fig. 1) it is evident that, E4 (Hills Evenness) and E5 (modified Hills Ratio) values (Table 1) for the sampling stations IV and V exhibit an even distribution of zooplankton species in that particular area. Also, Pileou's evenness component diversity (PE) is more similar to E4 and E5 which, is having an upper limit of N = 417. Further, E2 and E3 values also lie in the same curve with N = 437 and N = 417, indicating similarity between E1 and PE values which are known to be familiar indices (Ludwig & Reynolds 1988). Hence, these evenness indices are found to be compatible for a zooplankton data when the number of individuals is larger (in this case N>450). From the results, it is evident that, evenness indices are highly sensitive to the number of individuals/species in a sample.

The distance coefficients based on the resemblance functions quantify the similarity or dissimilarity between two sampling units/stations based on the observations over a set of descriptors. From the results depicted in Table 2, the E group (Euclidean) distances indicate that the sampling stations I and II are more similar (lowest distance values), followed by station numbers II and III. But the RED (Relative Euclidean distance) values indicate dissimilarity between station numbers I and II while E group distance values, showing similarity between station numbers III and IV. Further, RAD (relative absolute distance) values show dissimilarity between station numbers I and II and maximum similarity between II and IV. CRD (chord distance) and GDD (geodesic distance) values indicate maximum similarity between sam-

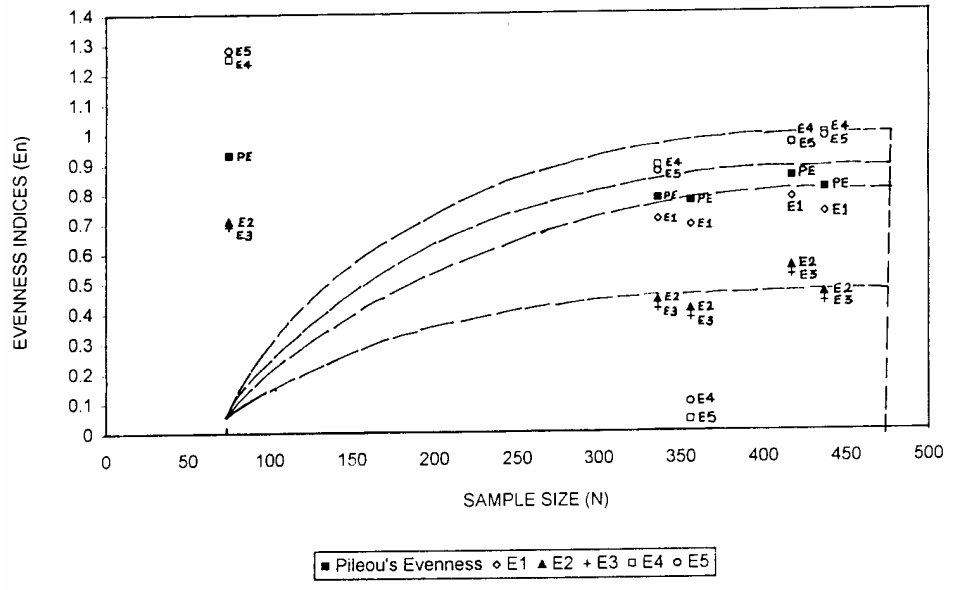


Fig. 1. Rarefraction curves for evenness indices for five sampling units in Andaman sea.

Table 2. Distance measures between five sampling stations based on the abundance for 19 commonly occurring zooplankton species of Andaman sea.

Stn. No.	ED	SED	MED	AD	MAD	PD	RED	RAD	CRD	GDD
I and II	48.08	2312	11.03	20	1.05	0.03	1.22	0.009	0.34	0.34
I and III	79.94	6391	18.84	-81	-4.5	-0.1	0.19	0.013	0.54	0.55
I and IV	123.29	15201	28.28	281	14.78	0.66	0.21	0	0.61	0.62
I and V	157.74	24885	36.19	-61	3.21	-0.07	0.4	0.03	1.11	1.18
II and III	78.17	6111	17.93	-101	-5.31	-0.13	0.19	0.01	0.52	0.53
II and IV	113.01	12773	25.92	261	13.73	0.64	0.24	-0.002	0.67	0.69
II and V	155.61	24217	35.7	-81	-4.26	-0.1	0.4	0.008	1.14	1.21
III and IV	136.13	18532	32.08	362	20.11	-0.7	0.15	0.07	0.56	0.57
III and V	138.13	19082	31.69	20	1.05	-0.03	0.31	0.001	0.92	0.96
IV and V	133.1	17718	32.28	-342	-20.11	-36.6	0.32	0.01	0.98	1.04
		E group distances						BC	RE group distances	

ED = euclidean distance (range zero to infinity), SED = squared euclidean distance (range zero to infinity), MED = mean euclidean distance (range zero to infinity), AD = absolute distance (range zero to infinity), MAD = mean absolute distance (range zero to infinity), PD = percent dissimilarity, RED = relative euclidean distance (upper limit 1.41), RAD = relative absolute distance (ranges from zero to 2), CRD = chord distance (upper limit 1.41), GDD = geodesic distance (upper limit 1.57).

pling stations I and II and least similarity between II and V. From the results, it is evident that E group, CRD and GDD distances show similar results for comparing the diversity patterns.

The similarity coefficients - Dice and Jaccard indices (Table 3) have been found to be statistically significant i.e., they were in the range of zero to one, indicating that these indices remain unbiased for zooplankton community even when the number of zooplankton samples is five (N = 5).

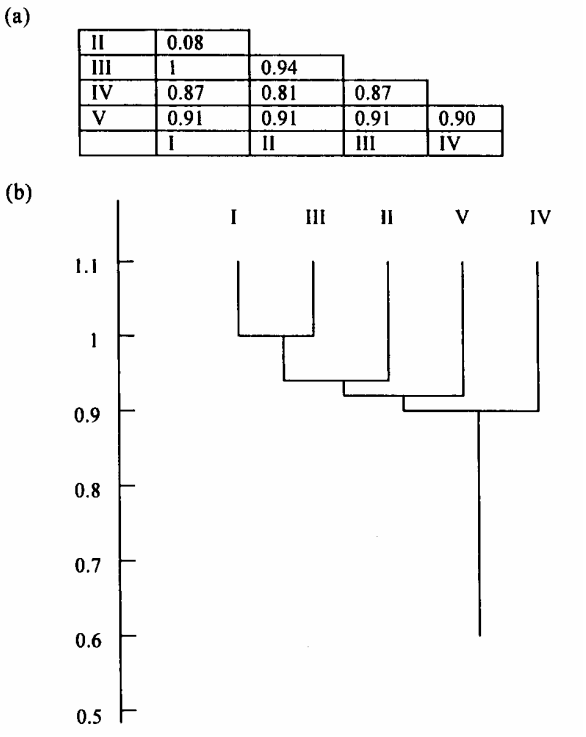


Fig. 2. Cluster analysis using simple linkage method for five sampling units in Andaman sea; (a) Similarity matrix, (b) Clustering with simple linkage method.

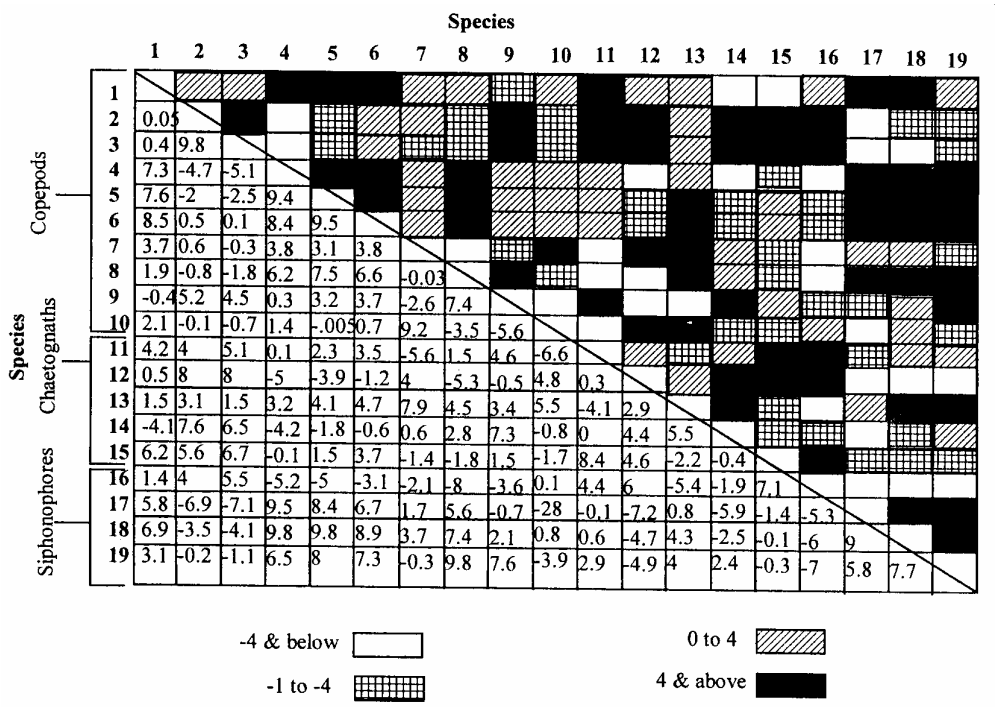


Fig. 3. The correlation matrix of the distribution of commonly occurring zooplankton species in Andaman sea at five sampling stations. The correlation indices are given to one decimal place and multiplied by 10. The zooplankton species are : Copepods: (1) *Euchaeta marina* (2) *Oncaea venusta* (3) *Oncaea media* (4) *Sapphirina nigromaculata* (5) *Rhicocalanus nasutus* (6) *Undinula vulgaris* (7) *Eucalanus attenuatus* (8) *Corycaeus specious* (9) *Corycaeus affinis* (10) *Pleuromamma xiphias* Chaetognaths (11) *Sagitta robusta* (12) *Sagitta nagae* (13) *Sagitta enflata* (14) *Sagitta pseudoserratodentata* (15) *Pterosagitta draco* Siphonophores: (16) *Praya reticulata* (17) *Chelophyes appendiculata* (18) *Diphyes dispar* (19) *Sulculeolaria biloba.*

Table 3. Similarity coefficients for 19 commonly occurring zooplankton species at five stations in Andaman sea.

	Similarity coefficients	
III and V	0.91	0.84
IV and V	0.90	0.82

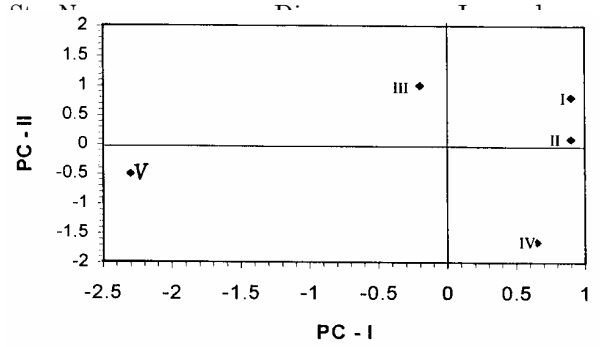


Fig. 4. Principal component ordination of the sampling units (SU's) in Andaman sea.

In simple linkage clustering, the sample (or the species) pair with the highest similarity values is chosen and then the group is further progressively enlarged by adding the sample or the species with the next highest similarity value to any of the clustered group. Here in our results, the similarity matrix (Fig. 2), the highest value is 1 for station numbers I and III and thus linked together at level 1. The second highest similarity value is 0.94 between the stations II and III, hence station II is linked to II and III, forming a group. The third highest link, at 0.91 is between II and IV, but these are already in the same group. Next new group is formed at 0.90 level between stations IV and V. Finally the clustering is completed at 0.90 level. Hence, it can be said that, clustering is influenced by the similarity value for a single pair among the members of each group.

The correlation matrix (Fig. 3) was computed for 19 commonly occurring epipelagic zooplankton

species using R type of analysis (species x species) to reveal the zooplankton species group within the habitats. The darker areas in the matrix indicate highly positive associations or similarity or correlation between the species, while the stripped areas in the matrix indicate partial correlation while the blank spaces indicate totally negative correlation between the zooplankton species.

Table 4. Eigenanalysis of the standardized 'A' matrix giving (a) species coordinates and (b) SU coordinates on four principal components.

(a) Species coordinates Principal components				
	Stations			
Zooplankton species	I	II	III	IV
1	-0.565	0.315	0.169	-0.774
2	0.444	0.862	0.233	0.073
3	0.512	0.846	0.131	-0.063
4	-0.96	-0.061	0.1	-0.256
5	-0.949	0.25	0.048	-0.185
6	-0.818	0.47	0.162	-0.288
7	-0.27	-0.035	0.958	-0.093
8	-0.809	0.332	-0.176	0.451
9	-0.254	0.768	-0.266	0.524
10	0.018	-0.266	0.943	-0.202
11	-0.014	0.677	-0.607	-0.416
12	0.613	0.477	0.597	-0.202
13	-0.385	0.319	0.774	0.388
14	0.242	0.639	0.229	0.694
15	0.147	0.683	-0.149	-0.7
16	0.708	0.184	-0.086	-0.676
17	-0.921	-0.285	-0.114	-0.238
18	-0.982	0.083	0.103	-0.132
19	-0.818	0.42	-0.218	0.328
Percent variance	40.27	64.36	82.9	100
(b) SU coordinates Principal components				
Sampling stations	I	II	III	IV
I	0.926	0.768	-0.616	-1.211
II	0.91	0.08	1.553	0.139
III	-0.163	1.053	-0.57	1.225
IV	0.67	-1.681	-0.595	0.277
V	-2.343	-0.22	0.229	-0.431

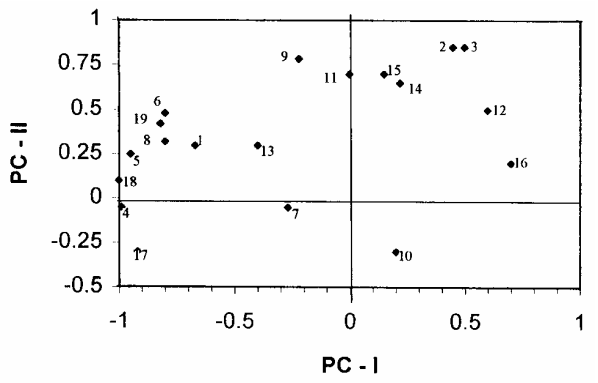


Fig. 5. Principal exponent ordination of 19 commonly occurring epipelagic zooplankton species in Andaman sea.

It is evident from the PCA as given in Table 4 and represented in Figs. 4 & 5 that relative distance between the two sampling stations indicates the similarity between them and respective coordinates. Similarly, closer the two zooplankton species, the more similar are their respective abundance in sampling stations. Chaetognath species - *Sagitta robusta* and *Pterosagitta draco* are abundant at stations I, II and III and less abundant at IV and V. Copepod species - *Oncaea venusta* and *Oncaea media* are abundant at station I and hence are positively correlated with Principal Components I and II. The zooplankton species *Euchaeta marina, Undinula vulgaris, Corycaeus specious, Sagitta enflata* and *Sulculeolaria biloba* are similar with regard to their relative abundance at stations I and II. The closeness of Stations I and II indicates similarities in zooplankton species composition.

It is apparent from our studies that, for analyzing the zooplankton community structure the Margalef (R1) and Menhinick (R2) indices can be taken as reliable criteria. The E group distances, CRD and GDD distances provide a more realistic value for analysis of zooplankton community structure and the degree of resemblance among sampling stations. In addition similarity coefficients (Dice and Jaccard similarity indices) could be also used for comparing similarity between two different sampling stations. The correlation matrix has been found to be better way of representing positive/negative associations

between the species. Principal component analysis exhibits the ecological closeness of different zooplankton across the sampling stations which could also be compared for consistency in community patterns.

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