International Journal of Marine Science 2016, Vol.6, No.28, 1-9
http://ijms.biopublisher.ca

Research Article Open Access

Abundance and Diversity of Zooplankton along the Gulf of Mannar Region, Southeast Coast of India

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International Journal of Marine Science 2016, Vol.6, No.28 doi: 10.5376/ijms.2016.06.0028
Received: 21 Apr., 2016
Accepted: 01 Aug., 2016
Published: 02 Aug., 2016

Preferred citation for this article:
Jeyaraj N., Ravikumar S., Rajthilak C., Kumar S.P., and Santhanam P., 2016, Abundance and Diversity of Zooplankton Along the Gulf of Mannar Region, Southeast coast of India, International Journal of Marine Science, 6(28): 1-9 (doi: 10.5376/ijms.2016.06.0028)

Abstract The study addresses the abundance and diversity of zooplankton along the Gulf of Mannar. Sampling was done from the nine stations. The samples were collected by horizontal hauls using the zooplankton net (150 µ m mesh size, 0.5 m mouth diameter and length 1.5 m) fitted with digital flow meter. From the study we recorded a total of 114 species of which the copepods formed the dominant group in all the stations. Which consists of *Acartia spinicauda, Acartia danae, Pseudodiaptomus aurivilli, Eucalanus elongatus, Labidocera acuta, Nannocalanus minor, Paracalanus parvus, Corycaeus speciosus, Dioithona rigida, Oithona similis, Metis jousseaumei, Favella brevis* and *Tintinnopsis directa.* The other dominant groups were barnacle nauplii, bivalves, gastropods larvae etc. The highest abundance (11,733 Nos./m^3) was recorded in station 2, while the lowest (1,913 Nos./m^3) was recorded in station 6. Diversity (H) was higher in the station 4 whereas the lowest diversity was observed from station 5 and no significant differences in Evenness (J) and Richness (SR) were observed between stations. A chemometric analysis such as cluster analysis (CA) and principal component analysis (PCA) reveals that, relationship among the zooplankton groups and studied stations. There was not any significant difference in zooplankton abundance between stations ($p > 0.05$).

Keywords Gulf of Mannar; Zooplankton; Species richness; Species association; Cluster analysis; Principal component analysis

1 Introduction

The biodiversity of a marine ecosystem plays an important role in its structure and function, and biodiversity information is increasingly used in management strategies for conserving harvested resources. Biodiversity comprises not only species variety, but also diversity in functional groupings and genetic variation within and among species (Gaston and Spicer, 2004). The Gulf of Mannar lies between India and Sri Lanka. It encompasses the territorial waters of the Southeast coast of India, from Dhanushkodi in the North to Kanyakumari in the South. They are located 2 to 10 km from the mainland along the 140 km stretch between Tuticorin and Rameswaram (Lat 8 ℅5'-9°15'N and Long 78°0'-79°16'E). The islands are classified into 4 groups, namely Mandapam group, Keelakarai group, Vembar group and Tuticorin group. They have fringing coral reefs and patch reefs, seaweeds, seagrasses and mangroves rising from shallow areas of sea-shore. Each having its own zonation pattern supporting its own characteristic communities (Kumaraguru *et al*., 2006). They consists of 117 species of corals, 641 species of crustaceans, 731 species of molluscs, 441 species of fin- fishes, 147 species of seaweeds and 52 species of seagrasses (Kumaraguru *et al*., 2006). In recent years, there is a tremendous increase in tourism along the Gulf of Mannar area. As a result, a large quantity of sewage has been dumping into the sea from the mainland. It may lead to change the physico-chemical characteristics of the coastal waters. However, zooplankton plays vital role in energy transfer in the aquatic biosphere and their ecology is of considerable interest in assessing the productivity of the sea (Hunter, 1981 and Jayasiri, 2007). Information dealing with the plankton of the coastal waters Gulf of Mannar that is of zooplankton is meagre and mostly limited to Maruthanayagam and Subramanian (1999) and Sridhar *et al*., (2008). As the study area is under the influence of anthropogenic pressure by means of receiving pollutants from nearby industries, the output of this study will act as a reference for coastal researchers and environmental planners for environmental impact assessment purpose.

2 Materials and Methods

Sampling was carried out by using a Hydro-Bios zooplankton net from nine stations [S1=Vembar; S2= Periyakulam; S3=Valinoakkam; S4=Ervadi; S5=Keelakarai; S6=Periyapattinam; S7=Pudumadam; S8= Rameswaram; S9= Dhanushkodi] (Fig. 1). The net had a mouth diameter of 0.5 m diameter and mesh size of 150 μm. A flowmeter was mounted at the center of the mouth to estimate the volume of the water filtered through the net. The net was towed obliquely from the surface. The collected plankton was transferred to 500 ml polythene containers and immediately preserved using 5% buffered formalin. Atmospheric and surface water temperature was measured using a standard centigrade thermometer. Salinity and pH were estimated with the help of a refractometer (ERMA, Japan) and ELICO grip pH meter respectively. The dissolved oxygen was estimated by the modified Winkler's method (Strickland and Parsons, 1972). The inorganic nitrate, nitrite, phosphate and reactive silicate were estimated according to Strickland and Parsons 1972. In the laboratory, preserved zooplankton samples were transferred into large petri dishes and the macro zooplankton like hydromedusa and large fish larvae were removed and then the specimens were sorted and identified up to species level by using standard monographs (Sewell 1929; Davis 1955; Kasturirangan 1963; Smith 1977; Santhanam and Srinivasan. 1994). For quantitative analysis, known quantity of zooplankton samples were placed on the *Sedgewick* Rafter *Counting chambers* and counts were converted into the number of individuals per m^3 for each station and they were observed under stereo zoom microscope (make: Nikon SMZ800). Biodiversity, taxa and evenness were calculated as per Shannon and Weaner (1949), Gleason (1922) and Pielou (1966).

Fig. 1 Map showing study area. S1=Vembar; S2=Periyakulam; S3=Valinoakkam; S4= Ervadi; S5= Keelakarai; S6= Periyapattinam; S7= Pudumadam; S8= Rameswaram; S9= Dhanushkodi

2.1 Statistical analysis

To find the similarity between the zooplankton groups a Hierarchical agglomerative clustering approach (CA) was employed and the results were illustrated as a dendrogram. CA was performed on the standardized data by means of Ward's method, using squared Euclidean distances as a measure of similarity. Principal component analysis (PCA) was employed with respect percentage of composition to correlate the relationship among the zooplankton and stations.

3 Results and Discussion

Atmospheric temperature was recorded in the range between 30.3 and 33.5 ℃ with an average value of 32.25 ± 1.05 ℃ from all the stations. The minimum temperature was observed at station 1 and maximum temperature was observed from station 8. Whereas Surface water temperature was observed in the range between 30.1 and 34 ℃ with on average value of 32.1 ± 1.16 ℃ with the minimum surface temperature was noticed in station 1 and

maximum was found at station 7 (Table 1). Generally, 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 variation of temperature is attributed by humidity and solar radiation (Das, *et al*., 1997). Low atmospheric temperature is mainly based on the high rate of humidity. However, high temperature might be due to higher solar radiation.

It was noticed that, pH of water varied from 7.08 to 8.60 with an average of 8.15 ± 0.34 around the study area. The maximum pH was noticed in station 3 which might be due to the influence of seawater penetration and high biological activity (Das *et al*., 1997) and the minimum value was observed in stations 5 &7 (Table 1). Variations in pH of oceanic waters are attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation and high biological activity (Subramanian and Mahadevan, 1999).

Table 1 Physicochemical and biological characteristics of chosen sampling sites in Gulf of Mannar region.

Station code	Station Name	At.Tem ℃	Wat. Tem ° C	pH	Salinity ‰	DO mg l^{-1}	Nitrite µmol $/l^{-1}$	Nitrate µmol/l^{-1}	Phosphate µmol/ l^{-1}	Silicate µmol/ l^{-1}	Density (No/m^3	Taxa (Nos)	Diversity	Evenness
S1	Vembar	30.3	30.1	8.3	35.0	5.4	2.64	6.30	08.5	12.0	8571	48	3.50	0.960
S2	Periyakulam	33.0	32.2	8.4	36.2	4.28	3.33	7.40	29.5	32.0	11733	56	3.42	0.949
S3	Valinoakkam	31.5	31.0	8.6	35.0	4.3	1.98	4.30	07.08	08.6	6347	52	3.29	0.942
S4	Ervadi	33.2	32.8	8.5	36.1	4.47	2.40	4.35	06.95	10.1	5520	83	3.97	0.966
S5	Keelakarai	32.5	32.0	7.8	35.0	4.36	3.18	4.15	10.05	07.9	4187	33	2.51	0.833
S6	Periyapattinam	33.0	34.0	8.1	33.0	5.2	1.58	3.50	09.15	08.0	1913	34	2.97	0.925
S7	Pudumadam	32.0	32.1	7.8	34.0	4.52	3.20	6.30	09.00	17.0	2767	36	2.75	0.892
S8	Rameswaram	33.5	33.2	7.9	34.5	5.3	3.40	6.80	08.50	21.0	7036	54	3.35	0.928
S9	Dhanushkodi	31.3	31.5	8.0	34.0	6.5	7.50	19.00	08.10	18.0	6000	43	3.17	0.929

The salinity of oceanic water acts as a limiting factor in the distribution of living organisms. Dissimilarity of salinity is caused by dilution and evaporation of oceanic water, which is most likely to influence the fauna (Gibson, 1982). From the nine study areas, salinity was observed to be within the range of 33 to 36.2 ‰ with an average of 34.75 ± 1.02 ‰ (Table 1). Among all the studied areas station 2 oceanic waters has maximum salinity, which might be attributed to the low rainfall, higher rate of evaporation at this station.

The observed dissolved oxygen concentration varied from 4.28 to 6.5mg l^{-1} with an average of 4.28 ± 0.77.

The minimum oxygen concentration was noticed at station 2 with maximum at station 9 (Table 1). The inorganic nitrate concentration was noticed in the range between 3.5 and 19 μmol/l^{-1} with an average of 6.9 ± 4.74 μmol/l^{-1} with the lowest nitrate content procured at station 6 and the highest value observed at station 9 (Table 1). The nitrite content was found from 1.58 to 7.5 μmol/L^{-1} with an average of 3.24 ± 1.71 μmol/l^{-1}. The lowest and highest nitrite was noticed at stations 6 and 9, respectively (Table 1). The phosphate concentration was found to vary between 6.95 and 29.5 μmol/l^{-1} with an average of 10.75 ± 7.09 μmol/l^{-1} with the minimum value at station 4, whereas the maximum value at station 2 (Table 1). The reactive silicate concentration varied from 7.9 to 32.0 μmol/l^{-1} with an average of 14.96±7.98 μmol/l^{-1}. Minimum silicate was recorded at station 2, whereas the maximum was obtained at station 5 (Table 1).

Gulf of Mannar region comprises 114 species of zooplankton belonging to diverse group's *viz*., 53 species of calanoid copepod, 17 species of cyclopoid copepod, 16 species of ciliata, 8 species of crustacean larval forms, 7 species of harpacticoid copepod, 2 species of chaetognatha, 2 species of mollusca, 2 species of echinodermates, 2 species of foraminifera, 2 species of chordates, 1 species of decapoda, 1 species of appendiculariae, 1 species of amphipods, 1 species of polychaete larvae, 1 species of ctenophores and 1 species of hydromedusae (Table 2). The maximum (83) species and minimum (34) species were observed from the stations 4 and 5 & 6 respectively. Among 114 species were found, the order copepoda was the most abundant taxon of which the calanoids *Acartia spinicauda, Acartia danae, Pseudodiaptomus aurivilli, Eucalanus elongatus, Labidocera acuta, Nannocalanus minor* and *Paracalanus parvus* the other species dominated were the cyclopoid *Corycaeus speciosus, Dioithona rigida, Oithona similis, Metis jousseaumei* along with *Favella brevis, Tintinnopsis directa*, barnacle nauplii, bivalves larvae and gastropods larvae (Table 2).

It is inferred from the present study that, zooplankton calanoid copepods has highest percentage composition 68.1 % at station 5 whereas cyclopoid copepod has 39.5% at station 7 (Fig. 2). 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), Parangipettai coast (Santhanam *et al*., 2013) and Southwest coast (Jeyaraj *et al*., 2015). Calanoid copepods were the most dominant group in all stations except station 3, both in terms of diversity and density during the investigation period. This might be due to calanoid copepods could able to adapt to the prevailing environmental situations besides continuous breeding habit (Kowenberg, 1993 and Chandramohan, *et al*., 1999).

The zooplankton taxa observed in various study sites ranged from 34 to 83 numbers with an average of 48.77 ± 15.51 numbers. The minimum taxa was observed in station 5 and the maximum was noticed in station 4 (Table 1). The zooplankton population density observed in various study sites. It was noticed that, population density ranged from 1913 to 11733 Nos./m^3 with an average of 6008 ± 2986 Nos./m^3. The maximum zooplankton density could be attributed to mainly by the nutrient enrichment and it might be due to high density of phytoplankton. But minimum might be due to oceanic currents and low primary productivity in the waters (Goswami, 1982 and Bhattathiri and Devassi, 1981). The variation of zooplankton density might be due to the Dial Vertical Migration of the species (DVM) and influence of oceanic currents (Pai *et al*., 2010). Higher population density with more number of copepods species were earlier observed by Maruthanayagam and Subramanian (1999) in Gulf of Mannar region.

The diversity and evenness of zooplankton are studied around the study sites. The diversity was ranged between 2.51 and 3.97 bits /individual with an average of 3.21 ± 0.43 (Table 1). The minimum diversity was observed from station 5 and the maximum was noticed from station 4. The high species diversity values at station 4 may be due to high copepod density which indicates the stable hydrological conditions and phytoplankton density (Goswami and Rao, 1981). Low species diversity at station 5 might be due to single species dominance. Evenness ranged between 0.83 and 0.96 with an average of 0.92 ± 0.04 an unequal distribution of the zooplankton species were observed at station 5 which causes the lowest evenness at this place. However, highest evenness values were obtained at station 4 which indicated that the species were equally distributed (Table 1)

Table 2 Distribution of zooplankton in various localities along the Gulf of Mannar region

	Zooplankton		
	Foraminifera	40	*C.discaudata*
1	*Globigerina bulloides*	41	*Centropages orsinii*
2	*Globigerina opima*	42	*Cosmocalanus darwinii*
	Protozoans – Ciliata	43	*Eucalanus elongatus**
3	*Favella brevis**	44	*Farranula gibbula*
4	*Favella philippinensis*	45	*Labidocera acuta**
5	*Evadne tergestina*	46	*L.pavo*
6	*Tintinnopsis conicum*	47	*L.bataviae*
7	*T.glans*	48	*L.madurae*
8	*T.karajcensis*	49	*L.minuta*
9	*T.lohmanni*	50	*L.pectinata*
10	*T.mortensenei*	51	*Nannocalanus minor**
11	*T.beroidea*	52	*Onychocorycaeus catus*
12	*T.butscheii*	53	*O.ovalis*
13	*T.cylindrica*	54	*Paracalanus parvus**
14	*T.directa**	55	*Paracalanus aculeatus*
15	*T.minuta*	56	*P.attenuatus*
16	*T.tocantinensis*	57	*Paracandacia simplex*
17	*T.bermudensis*	58	*Pontella spinipes*
18	*T.tubulosa*	59	*Pontellopsis armata*
	Calanoid copepod	60	*P.scotti*
19	*Acartia spinicauda**		
20	*A.danae**	61	*Rhincalanus cornutus*
21	*A.erythraea*	62	*R.nasutus*
22	*Calanopia elliptica*	63	*Sapphirina auronitens*
23	*C.aurivilli*	64	*S.nigromaculata*
24	*C.minor*	65	*Subeucalanus crassus*
25	*C.thompsoni*	66	*S.monachus*
26	*Candacia pachydactyla*	67	*Temora turbinata*
27	*Centropages calaninus*	68	*Tortanus barbatus*
28	*C.furcatus*	69	*T.gracilis*
29	*C.tenuiremis*	70	*Temora discaudata*
30	*Clausocalanus arcuicornis*	71	*T.stylifera*
31	*Pontella danae*		**Cyclopoid copepod**
32	*P.securifer*	72	*Bomolochus* sp.
33	*Pontellina plumata*	73	*Copilia vitrea*
34	*Pontellopsis herdmani*	74	*C.mirabilis*
35	*Pseudodiaptomus aurivilli**	75	*Corycaeus danae*
36	*P.serricaudatus*	76	*C.longistylis*
37	*Acrocalanus gracilis*	77	*C.speciosus**
38	*A.monachus*	78	*Sapphirina ovatolanceolata*
39	*Candacia bradyi*	79	*Oithona brevicornis*

Continued table 2

	Zooplankton		
80	*O.plumifera*		
81	*O.spinirostris*		
82	*Oncaea media*	101	Cladocerans
83	*Oncaea conifer*	102	Decapods and larvae
84	*O.venusta*	103	Isopods
85	*Oithona nana*	104	Mysids
86	*Dioithona rigida**	105	Cirriped larvae
87	*O.similis**	106	Zoae larvae
88	*O.simplex*		**Amphipods**
	Harpacticoid copepod		**Mollusca**
89	*Euterpina acutifrons*	107	Bivalves larvae*
90	*Macrosetella gracilis*	108	Gastropods larvae*
91	*Macrosetella* sp.		**Polychaete larvae**
92	*Metis jousseaumei**	109	Tomopteris sp.
93	*Microsetella norvegica*		**Ctenophores**
94	*M.oculata*		**Hydromedusae**
95	*M.rosea*		**Echinodermates**
	Chaetognatha	110	Siphonophores
96	*Sagitta enflata*	111	Stomatopods
97	*Sagitta robusta*		**Decapoda**
	Appendicularіae	112	*Lucifer* sp.
98	*Oikopleura* sp.		**Chordates**
	Crustacean larval forms	113	Fish larvae
99	Barnacle nauplii*	114	Fish eggs
100	Copepod Nauplii		

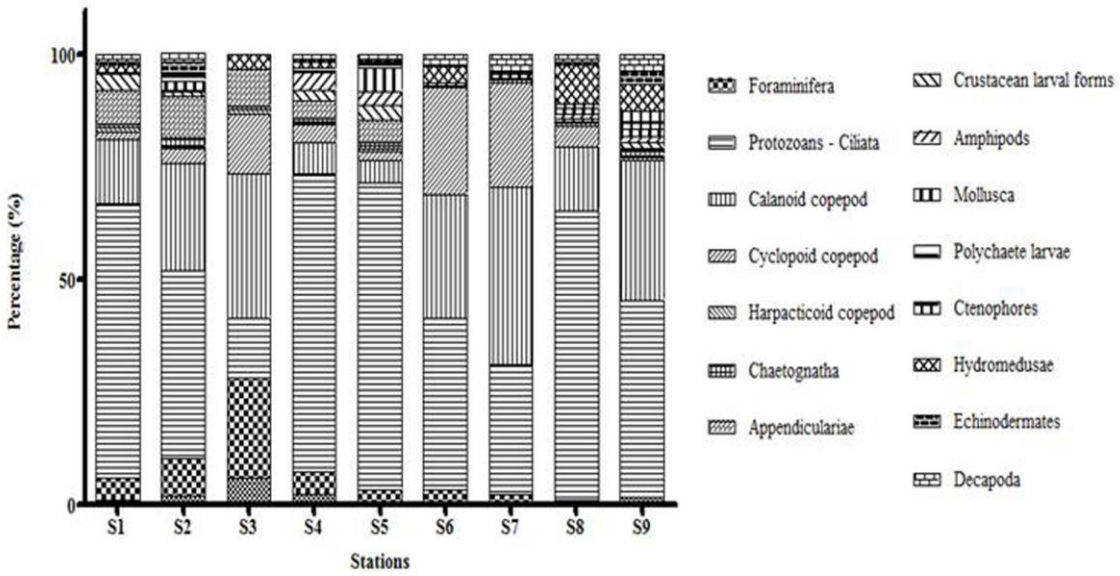

Fig. 2 Percentage contribution of dominant groups in different station

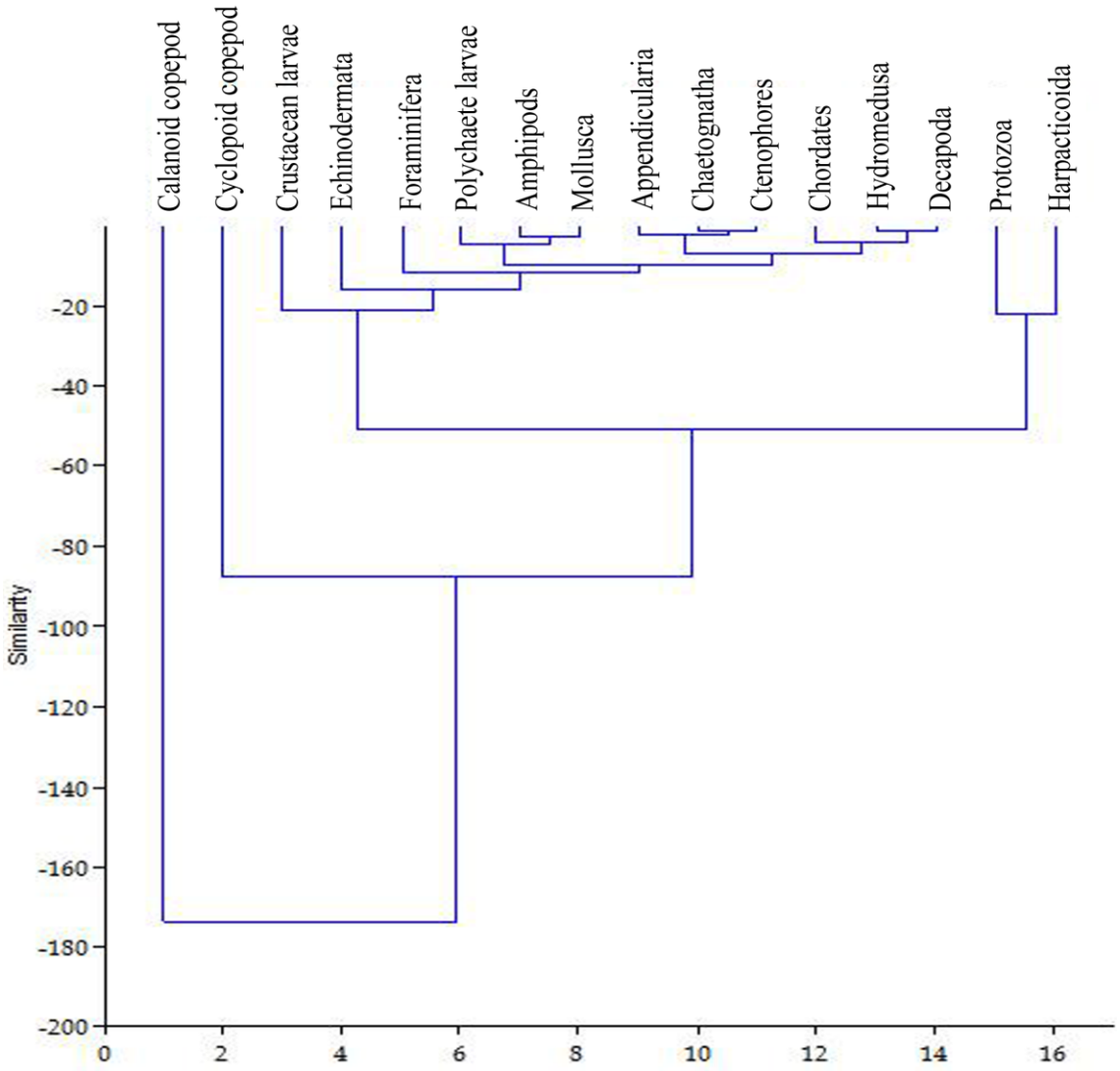

Fig. 3 Dendrogram of the sixteen groups of zooplankton species measured by Euclidean distances showing the degree of relative dissimilarity of distribution between species in the water masses of the study area

3.1 Species association

The Euclidean distance usually provides the similarity between two samples, and a distance can be represented by the difference between analytical values of the samples. The species association of the sixteen groups was measured by normalized Euclidean distances. A dendrogram showing the species association is illustrated in Fig.3. Species with similar horizontal distribution formed a cluster or close clusters. For instance, all the 16 zooplankton groups form 5 clusters with respect to percentage of distribution. Harpacticoid copepod and ciliate form a cluster, to which several groups are joined. These species are common to all water masses. Several species were extinct or rare in the coast but relatively most of the species were common and abundant in sampling sites, e.g., amphipods, molluska, appendiculariae, chaetognatha, ctenophores and decapoda, are joined to close clusters at the middle of the dendrogram. Among all species in linkage calanoid copepod and cyclopoid copepod has highest distance with all others which forms an outer group in the dendogram.

The present study also found that, Stations 1 and 3 are negatively correlating with each other with respect to distribution of zooplankton species Fig. 4. Stations 4 & 9 are positively correlating with each other indicates that the zooplankton species are similar with observe to their family member abundance at this stations. From this plot it was observed that stations 2, 1 and 6 are differing from all other sites. Statistical analysis reveals

environmental closeness of different zooplankton across the sampling stations. It is concluded, that the Gulf of Mannar region is considered as a rich bio-diversity hot spot for marine zooplankton. The present basic information of the zooplankton distribution and abundance would form a useful tool for further ecological assessment and monitoring of these coastal ecosystems.

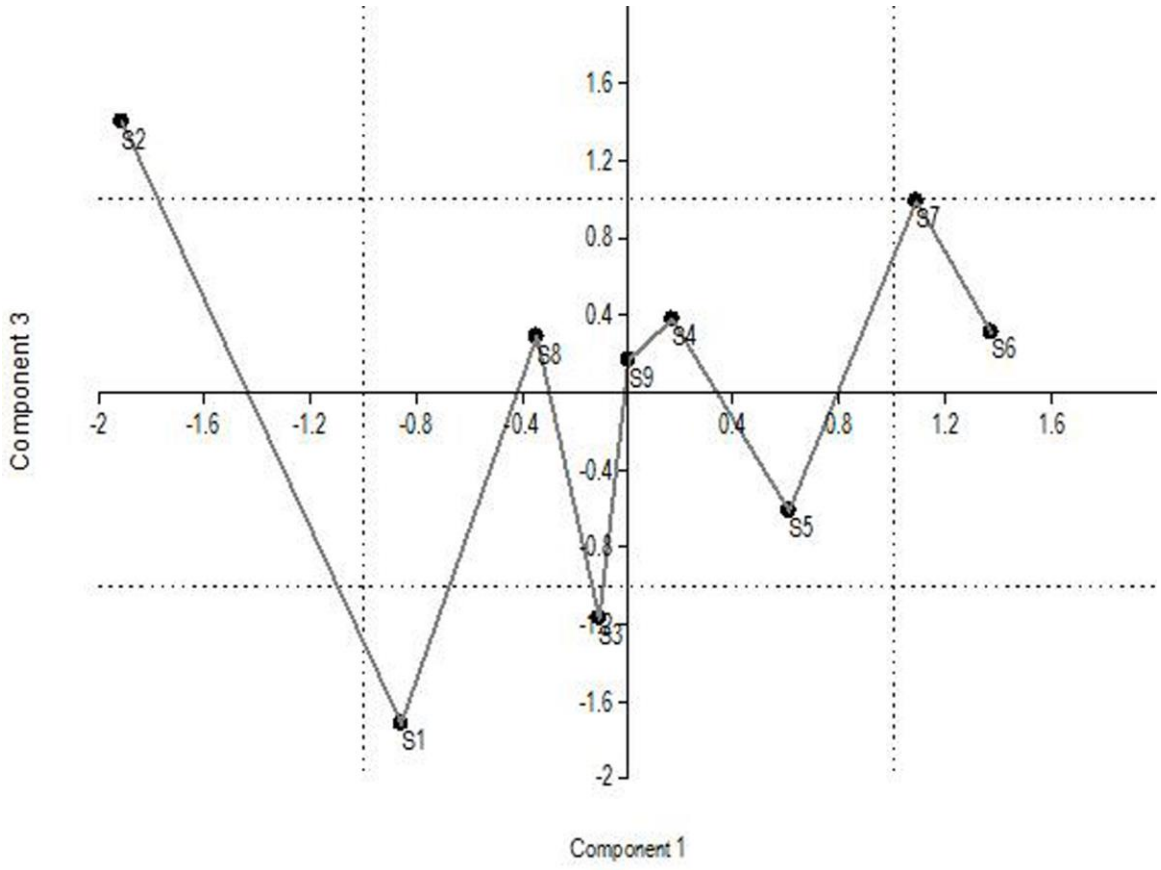

Fig. 4 PCs showing the degree of similarity in zooplankton faunas between stations

Acknowledgements

Authors are thanking the authorities of Alagappa University, Karaikudi, India and Bharathidasan University, Tiruchirappalli, India for providing required facilities. The author (N. Jeyaraj) expresses his gratitude to UGC, Government of India, New Delhi for financial assistance through Dr. D.S. Kothari Post-Doctoral Fellowship Programme.

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