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Seasonal variation of copepod community structure in Chavara coast along the Southern Kerala, India

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Authors Info

Jemi Job N.* and A. A. M. Hatha

Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Cochin-682 016, India

*Corresponding Author Email : jemicheeran@gmail.com

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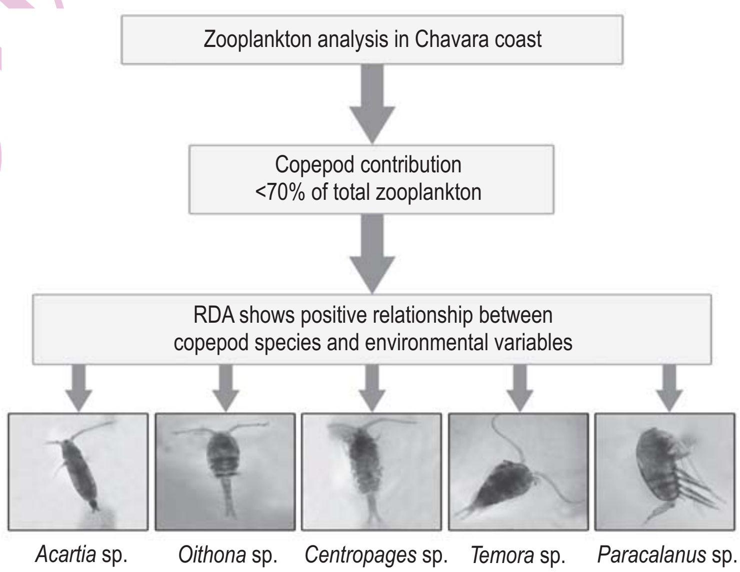
Abstract

Aim : To analyze whether the seasonally differing hydrographical parameters can alter chlorophyll a and zooplankton community distribution in Chavara coast during two different seasons.

Methodology : The samples were collected from 10 m and 30 m locations from Chavara during November 2013 (Northeast Monsoon), May 2014 (Spring Intermonsoon). The collected zooplankton samples were analyzed in a stereo zoom microscope and copepods were identified to the species level. The relation between environmental parameters and zooplankton abundance was examined using statistical tools.

Results : Water column was cool, nutrient rich and less oxygenated (subsurface) during November. Water column was characterized as warm, high saline and with less nutrients during May. These variations were closely linked with the increased cooling and continuation of weakened upwelling during November. Chlorophyll a was found two to five folds higher during northeast monsoon compared to the spring intermonsoon. Overall, 14 zooplankton groups were recorded in the present study of which copepods contributed more than 70% to the total zooplankton density. Zooplankton (3619.5 No.m-3) and copepod abundance (3212.8 No.m-3) was high in November. Non-metric Multidimensional Scaling (NMDS), Agglomerative Hierarchical Cluster Analysis (AHCA) on Bray–Curtis similarity clearly separated the samples of two clusters (30 m and 10 m) in two different seasons.

Interpretation : The copepods showed more similarity within season and more heterogeneity between two seasons. Some copepod species showed positive relationship with the environmental variables.



Introduction

The zooplankton often constitutes a substantial component of the plankton community in marine environments (Kane 2007; Keister *et al*., 2012). Copepods, the predominant taxon in mesozooplankton community support the transfer of nutrient and energy from phytoplankton and bacteria to higher trophic levels in marine pelagic food webs (Kobari *et al*., 2008; Abe *et al*., 2013). Copepods are sensitive to water mass properties, which are the important factors that affect their spatial distribution and abundance (Hwang and Wong, 2005; Hwang *et al*., 2006). This implies that some copepod species can be used as biological indicators of various water masses (Hwang *et al*., 2006; Hwang *et al*., 2007). Copepods show spatial and temporal variations in their distribution patterns (Hsiao *et al*., 2011; Naz *et al*., 2012; Balqis *et al*., 2016).

Temporal changes in distribution and abundance of zooplankton may be caused by variations of many abiotic and biotic factors. Planktonic copepods are strongly related to the hydrographic characteristics of marine environment. Hydrographical parameters between the seasons showed significant differences in southwest coast of India related to various physical processes like upwelling, riverine influx and summer stratification etc. (Madhupratap *et al*., 1996; Jyothibabu *et al*., 2008). Chavara coast is a specialized ecosystem due to the formation of frequent occurrence of mud bank and one of the major fishing sites of southwest coast of India. Coastal waters of Chavara has been subjected to pollution due to discharge from the titanium dioxide producing industry and the sewage discharge also causes severe damage to the fishery resources of this region. This region is world famous for its rich heavy mineral resources like rutile and ilmenite. Seasonal variation of copepod community structure was studied by different authors in different regions of India (Perumal *et al*., 2009; Santhanam *et al*., 2012; Stephen et al., 2013; Sanu *et al*., 2014). However, the information on zooplankton and copepod species diversity from the coastal waters of Southern Kerala (Robin *et al*., 2009; Jeyaraj *et al*., 2014; Vineetha *et al*., 2015; Cleetus *et al*., 2016) is still sparse. The studies on copepod dynamics from Chavara were limited to the observations of Robin *et al*. (2009). Hence, the present study was undertaken in Chavara coast along the Southern Kerala to study the influence of hydrography on zooplankton distribution and copepod species diversity during two different seasons.

Materials and Methods

The southwest coast of India is an important stretch of coastline having richer marine fauna and flora. Seasonally reversing monsoons is a characteristic feature of southwest coast of India. Two locations along Chavara transect, which at 10 m location - latitude 9°00'044"N and 76°29'454"E longitude; 30 m location – latitude 9°00'041"N and 76°21'615"E longitude were selected for the study (Fig. 1). The Chavara coast which covers coastal stretch of 22 km length from Neendakara to Kayamkulam is world famous for its rich heavy mineral resources. Sampling was carried out in northeast monsoon and spring intermonsoon. At each location, water samples were collected from surface, middle (5 m in 10 m location and 15 m in 30 m location) and bottom (9 m in 10 m location and 28 m in 30 m location) using 5 l Niskin sampler (General Oceanics, USA) for measuring chlorophyll a, dissolved oxygen and nutrients. The vertical distribution of physical parameters such as salinity and temperature were recorded by factory calibrated sensors. Nitrate was measured by Grasshoff's method (Grasshoff *et al*., 1983). The dissolved oxygen was estimated by Winkler's modified method (Grasshoff *et al*., 1983) and the extracted chlorophyll a was measured by a Trilogy Turner fluorometer following the standard procedure (UNESCO, 1994).

Zooplankton samples were collected by horizontal hauls using WP-2 net (200 µm mesh size), attached with a calibrated digital flow meter (Hydro-bios, Germany). After each haul the zooplankton sample was transferred into clean 0.5 l plastic containers and the samples were fixed in (4 – 5%) buffered formalin. Zooplankton sub-samples (25%) were sorted and analyzed in a stereo zoom microscope (Model – Motic DMW – 143 – FBGG) and taxonomic group level abundance was estimated (Postel *et al*., 2000). Among various taxonomic groups, copepods were further analyzed and identified to the species level using standard keys (Kasturirangan, 1963; Conway *et al*., 2003). The zooplankton diversity was represented using three common diversity indices - species diversity index (H'), species richness (d), evenness index (J') and were calculated by using the formulas of Shannon Wiener (1963), Margalef (1968) and Pielou (1969) respectively. In order to study the spatial and seasonal variation in environmental and biological parameters in Southwest coast of India (Chavara) parametric ANOVA was carried out on data having normal distribution. The tests of normality, parametric and nonparametric ANOVA were carried out in XL stat pro - software package.

Multivariate analysis was used to understand the relationship among the physicochemical, mesozooplankton communities and copepod orders (PRIMER 6). Hierarchical agglomerative method of cluster analysis was used to segregate different sampling locations based on their environmental and biological parameters. The results were represented by a dendrogram with x-axis representing the full set of stations and y-axis defining the similarity level at which the samples or groups were fused (Jagadeesan *et al*., 2013). Cluster analysis followed by Non-metric multidimensional scaling plots (NMDS) was used to segregate locations with similar properties. Copepod species abundance data were initially log (X+1) transformed to normalize the differences in numerical abundance (Clarke and Warwick, 2001). The spatial grouping of locations in different seasonal collections was done by the Bray - Curtis similarity matrix using group average method. To identify significant assemblages of stations ($p<0.01$) similarity profile (SIMPROF) permutation test was also performed (Clarke and Gorley, 2006). The relationships between important species of copepods and environmental variables were analyzed using RDA (CANOCO 4.5). The biological variables were log transformed and centered prior to the analysis. Monte Carlo permutation tests (499 unrestricted permutations) ($p < 0.05$) was used to test the ordination significance. The samples were displayed by points and species and quantitative environmental variables were shown by arrows in triplots of RDA.

Results and Discussion

Seasonal changes in waves and currents are experienced by the monsoon dominated coast, Chavara in Southwest coast of India (Hameed *et al*., 2007). The general current pattern explains the stronger southerly currents during monsoon and weaker northerly currents during fair weather in Chavara. Northeast monsoon period was reported as weak and moderate upwelling season near the southwest coast (between 8° N and 14° N latitudes) in the study of Smitha *et al*. (2014). The hydrographical changes may influence the biological factors in coastal waters of Chavara. Salinity ranged from 33.26 ppt to 35.52 ppt in the present observations (Table 1). Salinity did not show much variation between the collections during May and November (ANOVA, P>0.05). During May (spring intermonsoon), surface salinity was high compared to November, whereas in the bottom salinity was high during November. The high salinity of water during May (spring intermonsoon period) is the normal nature of the Arabian Sea (Shenoi *et al*., 2005) and the salinity of the coastal waters may go down due to riverine inputs from the adjacent areas and littoral inputs from small canals. During the northeast monsoon period the coastal water salinity becomes intermediate between the spring intermonsoon and southwest monsoon period, this observations were in accordance with the earlier observations like Madhuparatap *et al*. (1990), Madhuparatap *et al*. (2001) from the south eastern Arabian Sea.

The spatial distribution of the temperature showed minor differences (< 0.5°C), but the temporal distribution of the temperature showed ~5°C variations (Table 1) between November and May. Water column was warmer during May compared to November. In May, dissolved oxygen was found ~ 5.0 mg l^{-1} in surface, middle and bottom layers of 10 m and 30 m locations. During November, surface DO was >5.0 mg l^{-1}, but in bottom layers DO concentrations was low and found ~3.2 mg l^{-1} at 10 m and 30 m locations respectively. In the month of November it was found 5.74 mg l^{-1} and 5.15 mg l^{-1} in 10 m and 30 m locations respectively. The highest concentration of dissolved oxygen was recorded during the northeast monsoon (November). Nitrate showed noticeable differences between May and November (ANOVA, P<0.05) in all three layers. The warm waters and fewer nutrients during the spring intermonsoon period represent the oligotrophic nature of the Arabian Sea (Wiggert *et al*., 2005). Similar kinds of observations, like low concentrations of nitrate, warmer water temperature and oligotrophic nature during the spring intermonsoon period was reported by Madhupratap *et al*. (1990, 1996), Smith *et al*. (1998) and Sarangi *et al*. (2011). The low concentrations of nitrate, warm temperature and high salinity were found during May than November. This represents the oligotrophic or low productivity in Chavara station during spring intermonsoon in the present study.

In general, nitrate concentration was two to five folds high during November compared to May (Table 1). During May, nitrate was found <1 µM and in November it was >3 µM. The high concentrations of nitrate and less sea surface temperature during

Table 1 : Distribution of physico chemical parameters and chlorophyll a in Chavara during November 2013 and May 2014

Parameters	Depth	November		May	
		10 m	30 m	10 m	30 m
	S	33.26	34.35	34.65	35.52
Salinity (ppt)	M	34.1	34.39	34.81	34.8
	B	35.12	35.16	34.91	34.98
	S	26.3	26.4	31.5	30.9
Temperature (°C)	M	25.6	25.2	30.1	30.3
	B	24.8	24.3	29.8	29.7
	S	5.74	5.15	5.6	5.05
DO (mg l^{-1})	M	4.89	4.89	5.12	4.98
	B	3.15	3.05	5.05	4.85
	S	3.69	5.91	0.14	0.11
Nitrate (µM)	M	2.65	4.95	0.32	0.19
	B	3.56	3.25	0.46	0.25
	S	4	5.96	1.3	0.4
Chlorophyll a	M	3.12	3.19	0.89	0.65
(mg m^{-3})	B	3.09	3.18	1.1	0.98

S – Surface, M – Middle and B – Bottom

Table 2 : Zooplankton groupwise abundance (No. m^{-3}) in the two different seasonal collections in Chavara transect during November 2013 and May 2014

Groups	November		May	
	10 m	30 m	10 m	30 m
Medusae	1.3	2.1	-	-
Siphonophores	2.6	0.6	3.2	1.6
Chaetognaths	65.3	72.3	204.8	70.4
Copepods	3212.8	1510.4	1003.2	406.4
Cladocerans	235.2	222.2	98.4	20.8
Amphipods	-	-	1.6	-
Appendicularians	21.1	9.1	22.4	11.2
Lucifer	7	0.6	1.6	1.6
Mysid	6.4	-	1.6	1.6
Thalacians	-	-	1.6	1.6
Decapod larvae	49.9	0.3	64	3.2
Molluscan larvae	-	5.1	1.6	8
Fish eggs	17.9	35.5	12.8	-
Fish larvae	-	-	8	-
Total	3619.5	1858.2	1424.8	526.4

(0 - denotes absence)

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Table 3 : Spatial distribution of copepod species in the two different seasonal collections in Chavara transect during November 2013 and May 2014

Groups	Nov		May	
	10 m	30 m	10 m	30 m
Medusae	1.3	2.1	-	-
Undinula vulgaris	++	++	+	+
Rhincalanus cornutus	-	++	-	-
Rhincalanus nasutus	-	+++	-	-
Pareucalanus elongatus	+	+++	+	-
Pareucalanus attenuatus	++	++	++	+
Paracalanus parvus	***	**	*	++
Acrocalanus gibber	++	++	++	+
Acrocalanus gracilis	++++	+++	++	+
Centropages orsini	***	++++	++	++
Centropages furcatus	-	-	++	-
Centropages tenuiremis	*	-	++	++
Pseudodiaptomus aurivilli	-	-	+	-
Pseudodiaptomus serricaudatus	+	+	+	-
Temora turbinata	***	++	++	+
Temora stylifera	-	++	++	+
Temora discaudata	-	+	+	-
Candacia discaudata	-	++	-	-
Candacia bradyi	++	-	-	-
Calanopia minor	-	-	-	+
Labidocera acuta	+	+	++	+++
Labidocera pectinata	+	++	*	++
Labidocera minuta	-	+	-	+
Pontellopsis macronyx	-	+	+	-
Pontellina plumata	-	++	+	-
Acartia erythraea	++	+++	++	++
Acartia danae	+++	**	++	+
Macrosetella gracilis	++	++	+	+
Euterpina acutifrons	+++	-	+	-
Oithona spinirostris	+++	-	-	+
Oithona plumifera	++	-	+	+
Oithona rigida	++	-	++	+
Oithona brevicornis	-	-	+	-
Oithona similis	++++	-	+	+
Oncaea venusta	+++	++	+	+
Corycaeus speciosus	++	++	++	++
Corycaeus danae	+	-	++	-
Corycaeus catus	++	+++	+++	+++
Corycella gibbula	-	-	-	+
Sapphirina ovatolanceolata	-	-	-	+
Monstrilloids	++	++	-	-

denotes copepods density >0.1 to ≤10; ++ denotes 10.1 to ≤50; +++ denotes 50.1 to ≤100; ++++ denotes 100.1 to ≤ 200; * denotes 200.1 to ≤ 300; **denotes 300.1 and ≤ 400; *** denotes 400.1 to ≤500; 0 denotes absence

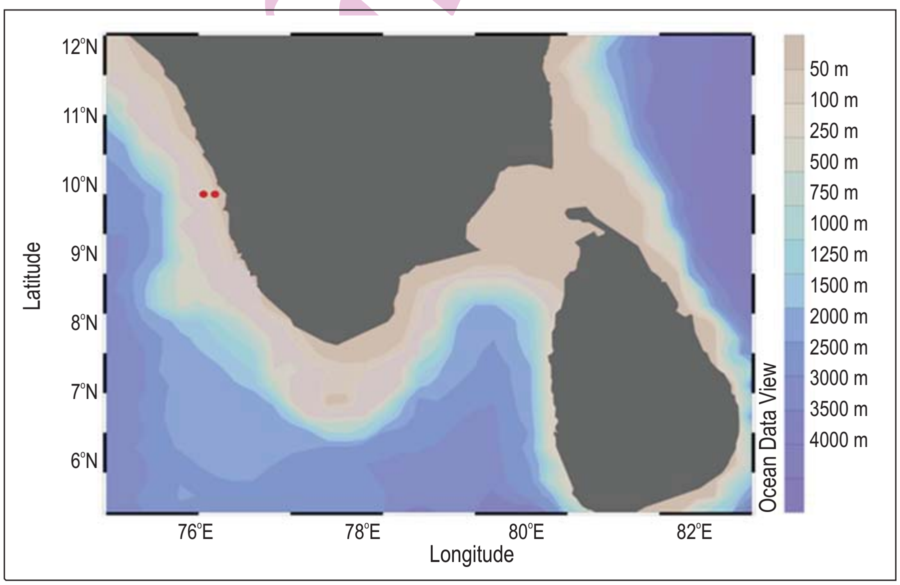

Fig .1 : Map showing the geographical locations of the sampling stations

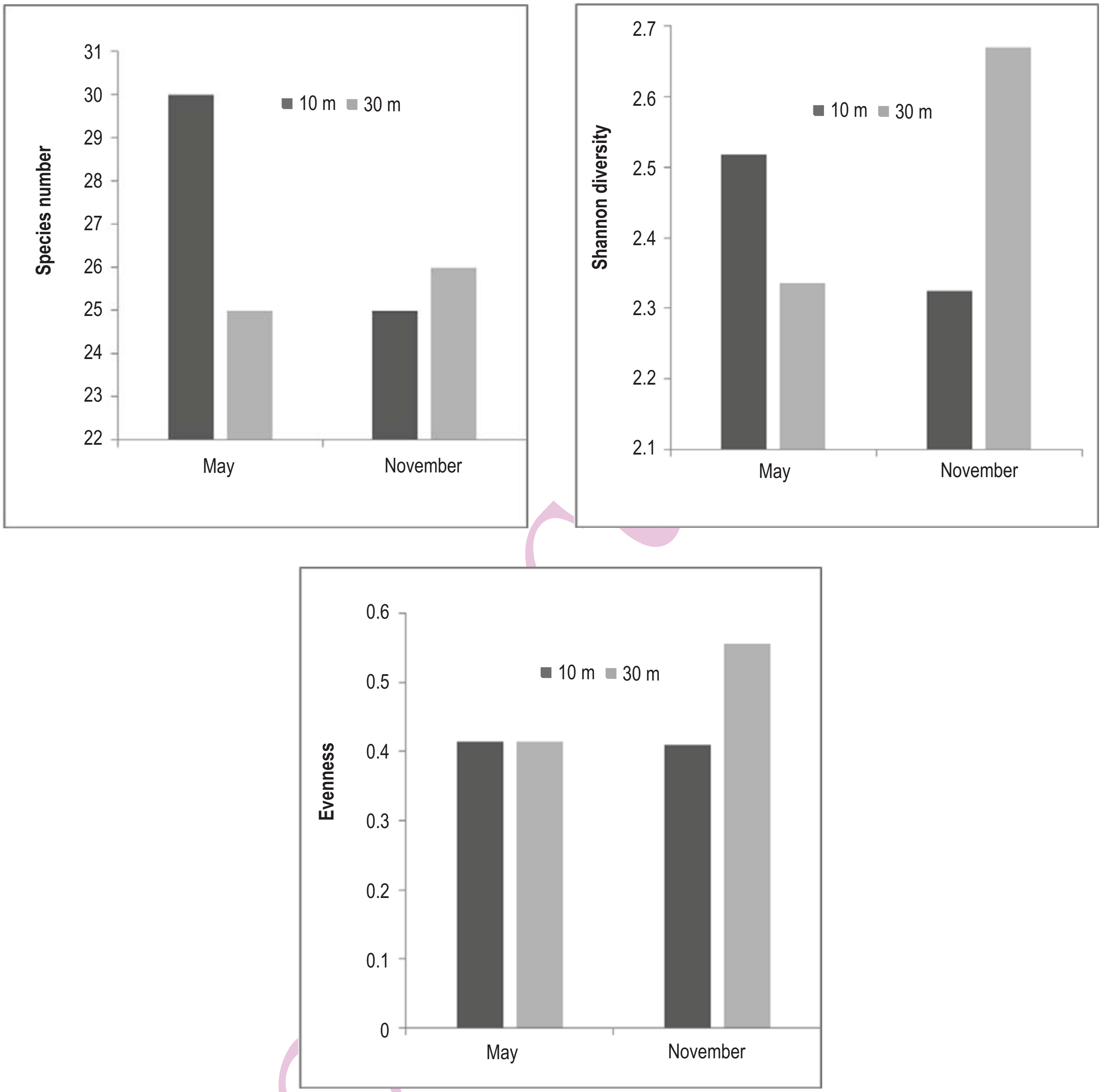

Fig. 2 : Diversity indices of copepod community structure in two different seasonal collections from the Chavara transect during November 2013 and May 2014 (a) Species richness (b) Shannon diversity and (c) Pielous evenness

the northeast monsoon period in the Arabian Sea are the result of the winter cooling (Saher *et al*., 2007; Gerson *et al*., 2014). Chlorophyll a is considered as the representation of the phytoplankton biomass and production. In the present study the high chlorophyll a concentrations during November (Northeast Monsoon) from the Chavara transect as the result of the winter cooling and weakened upwelling. The differences in nutrients influenced the Chlorophyll a distribution in the study area. The temporal distribution of Chlorophyll a showed the significant differences (ANOVA, P<0.05). Chlorophyll a concentrations ranged from 0.40 to 1.30 mg. m^{-3} in May and 3.09 to 5.96 mg. m^{-3} in November (Table 1). The maximum chlorophyll a concentration was found during November and it was less during May.

Zooplankton abundance ranged from 526.4 No.m^{-3} to 3619.5 No.m^{-3} (Table 2) and showed remarkable seasonal pattern in the present study. High zooplankton abundances during November (two folds higher) and the lowest zooplankton production during May were found in Chavara station. In altogether, 14 zooplankton groups were reported in

Table 4 : Results of SIMPER analysis represent the similarity within and between the clusters in Chavara transect during November 2013 and May 2014

(a) Group 1 members (the stations of 10 m and 30 m during May) showed the 47.42 % similarity within observations

Species	Av. Abund	Av. Sim	Contrib%	Cum.%
Labidocera pectinata	146.24	15.53	32.76	32.76
Centropages orsini	55.75	10.86	22.91	55.67
Labidocera acuta	61.33	5.97	12.59	68.26
Paracalanus parvus	118.28	4.6	9.69	77.95
Acartia erythraea	19.95	3.9	8.23	86.18
Centropages tenuiremis	18.79	2.14	4.52	90.7

(b) Group 2 members (the stations of 10 m and 30 m during November) showed the 60.32 % similarity within observations

Species	Av. Abund	Av. Sim	Contrib%	Cum.%
Paracalanus parvus	654.23	13.68	22.68	22.68
Centropages tenuiremis	262.72	10.83	17.95	40.63
Centropages orsini	274.17	6.84	11.34	51.97
Acartia danae	182.29	5.9	9.78	61.75
Acrocalanus gracilis	135.68	5.67	9.4	71.15
Oithona similis	113.63	4.76	7.9	79.04
Oithona spinirostris	90.6	3.63	6.02	85.06
Acartia erythraea	60.5	2.04	3.38	88.44
Pareucalanus attenuatus	54.53	1.81	3.01	91.45

Species	Group 1 Av.Abund	Group 2 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paracalanus parvus	118.28	654.23	17.66	1.66	22.82	22.82
Centropages tenuiremis	18.79	262.72	9.28	4.46	11.99	34.81
Temora turbinata	16.67	294.25	8.35	0.94	10.8	45.61
Centropages orsini	55.75	274.17	7.3	2.56	9.43	55.04
Acartia danae	30.79	182.29	6.4	1.51	8.28	63.32
Acrocalanus gracilis	6.93	135.68	5.06	2.73	6.55	69.87
Labidocera pectinata	146.24	10.16	4.99	1.68	6.45	76.32
Oithona similis	1.43	113.63	4.3	3.88	5.56	81.87
Oithona spinirostris	0.23	90.6	3.58	2.52	4.63	86.5
Labidocera acuta	61.33	8.55	2.15	1.19	2.78	89.28
Pareucalanus attenuatus	2.59	54.53	2.15	1.77	2.77	92

Av. Abund: Average abundance, Av.Sim: Average similarity, Contrib%: Contribution percentage, Cum. %: Cumulative percentage, Av. Diss: Average dissimilarity, Diss/SD: Dissimilarity/Standard Deviation

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the present study (Table 2), copepods contributed more than 70% to the total density. Copepods contribution to total density was high in the month of November at depth. 10 m. In January collection at 10 m depth chaetognaths contributed 13-14 % of zooplankton, while in November their contribution reduced to less than 10%. Decapod larvae contributed 4.4% to the total density in the month of May at the depth of 10 m, whereas at other stations their contributions never exceeded more than 2%. Cladocerans distribution showed clear seasonality; in May their contribution was found to be 6.6% and 3.95% in 10 m and 30 m locations, respectively. But in the month of November their contribution was found 11% at 30 m and 10 m locations. Fish eggs density was high in November as compared to May. Similar observations about seasonal variations of zooplankton production between the seasons were reported from southwest coast of India (Rajagopalan *et al*., 1992; Rao *et al*., 1992). In the present study, the copepods are the most dominant zooplankton groups. Similar kinds of observations about the dominance of copepods to the total density were reported by Perumal *et al*. (2009), Fernandes and Ramaiah (2009), Jagadeesan *et al*. (2013) and Jayaraj *et al*. (2014).

Copepods density ranged between 406.4 No.m^{-3} to 3212.8 No.m^{-3} and it was higher in the month of November. The minimum copepods density 406.4 No. m^{-3} was reported in May at the depth of 30 m. b) In the present study, altogether 40 species were reported, among these, 26 belong to the order Calanoida, 2 belonged to order Harpacticoida, 5 species belonged to Cyclopoida order and 7 species belonged to the order Poecillostomatoida. In Calanoida order, 9 families were found such as Calanidae, Eucalanidae, Paracalanidae, Centropagidae, Pseudodiaptomidae, Temoridae, Candaciidae, Pontellidae, Acartiidae. In Harpacticoida order, 2 families naming, Macrosetellidae, Tachidiidae were found. Copepod species richness was high in May at 10 m coastal locations. Species richness was comparable at 30 m location of May and 10 m location of November. Individual species distribution showed remarkable temporal variations. The individual species density and their distribution were shown in Table 3. Shannon diversity was high during May at 10 m locations while in November it was high at 30 m locations. Pielous evenness was high at 30 m locations compared to the 10 m locations in November (Fig. 2). The phytoplankton size, predator availability, toxic substances, dissolved gases, quality and quantity of the food materials available from their surroundings

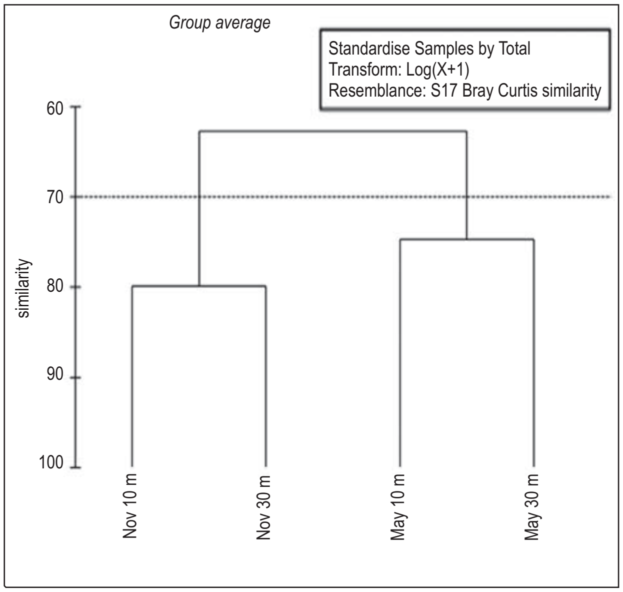

Fig. 3 : Bray - Curtis similarity index based group average liknage dendrogram of cluster analysis from Chavara transect

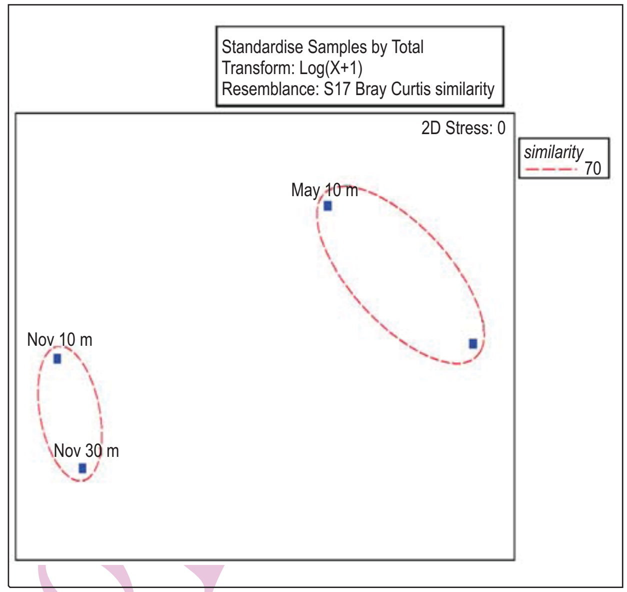

Fig. 4 : Cluster overlaid two dimensional NMDS plot visualizes the spatial assemblages of the locations and observations based on their relatedness to the dominant copepod species distribution in Chavara

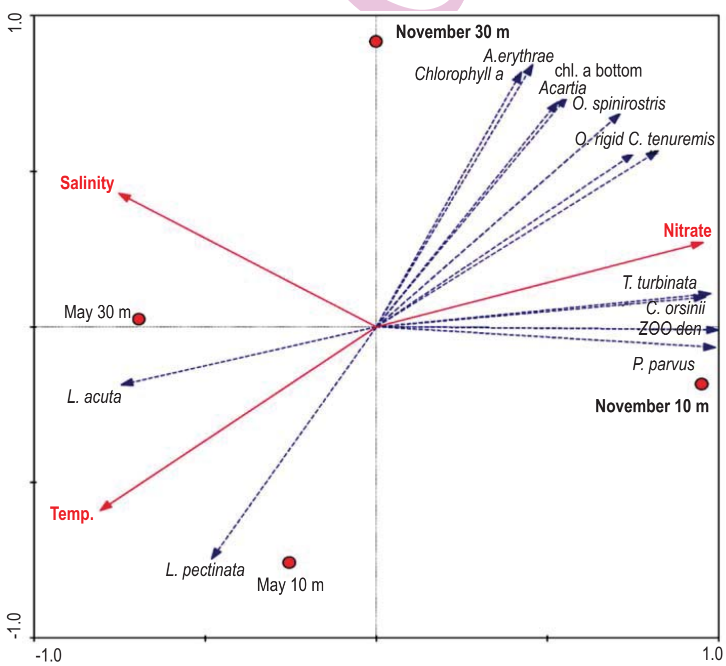

Fig. 5 : RDA triplot visualizes inter relationships within and between the biological and environmental variables in Chavara transect

influence the distribution of copepods (Jagadeesan *et al*., 2013). During the Spring Intermonsoon period May and later Southwest Monsoon period showed differences in the copepod species distribution, especially that of the *Temora turbinata*, *Oithona similis*, *Centropages orsini*, *Paracalanus parvus*, *Centropages tenuiremis*, *Corycaeus catus* and *Acartia erythraea* were significantly differed. The abundance of the *Temora turbinata* was found to be higher during the Northeast Monsoon period. These kinds of the seasonal pattern in the copepod species distribution was reported from the Indian waters (Madhupratap *et al*., 1990; Gowsami and Padmavati, 1996; Madhuparatp *et al*., 2001; Rakesh *et al*., 2006; Rakesh *et al*., 2008; Jagadeesan *et al*., 2013).

In cluster analysis, the members within the cluster showed more similarity while between the clusters they showed more heterogeneity nature. Spatial and temporal similarity of species distribution of the observations from the Chavara transect (November 2013 and May 2014) were grouped into two clusters at 70% similarity level (Fig. 3, 4). Cluster 1 included the observations of 10 m and 30 m locations of May 2014 and cluster 2 included the observations of 10 m and 30 m locations of November 2013. The grouping significance was tested in SIMPROF which showed that the grouping pattern was significant analysis ($P<0.01$). Cluster 1 group members (stations at 10 m and 30 m during May) showed 47.42 % similarity within observations. *Labidocera pectinata*, *Centropages orsini*, *Labidocera acuta*, *Paracalanus parvus*, *Acartia erythraea*, *Centropages tenuiremis* were the most important species in cluster 1. Among these, distribution of *Labidocera pectinata* and *Centropages orsini* showed more contribution to the similarity percentages such as 15.53% and 10.86% respectively. In cluster 2, the important species were *Paracalanus parvus*, *Centropages tenuiremis*, *Centropages orsini*, *Acartia danae*, *Acrocalanus gracilis*, *Oithona similis*, *Oithona spinirostris*, *Acartia erythraea* and *Pareucalanus attenuatus*. Species distribution between the locations of 10 m and 30 m during November showed 60.32 % similarity.

At Chavara station members of cluster one and two showed 77.37% dissimilarity. In these clusters, the distribution of following species were more dominant and altogether they contributed 90% to dissimilarity contribution such as *Paracalanus parvus*, *Centropages tenuiremis*, *Temora turbinata*, *Centropages orsini*, *Acartia danae*, *Acrocalanus gracilis*, *Labidocera pectinata*, *Oithona similis*, *Oithona spinirostris*, *Labidocera acuta* and *Pareucalanus attenuatus*. There was 2-3 folds variation in the abundances of *Paracalanus parvus*, *Centropages tenuiremis*, *Temora turbinata*, *Centropages orsini*, *Acartia danae*, *Acrocalanus gracilis*, *Oithona similis*, *Oithona spinirostris* and *Pareucalanus attenuatus* in cluster 2 locations. The abundances of *Labidocera acuta*, *Centropages orsini* and *Labidocera pectinata* were relatively high in the cluster 1 locations. The SIMPER (Similarity Percentage) analysis was performed along with the cluster mentioned above. This represents the similarity level within the cluster and their contributions of the species into that similarity level. Furthermore, it provides information about differences in similarity between the cluster and dominant members which one responsible for that dissimilarity. The results of SIMPER analysis is presented in Table 4. Table 4a and 4b provide information about similarity percentage within the cluster members and the species contributed in each cluster. Table 4c shows information about dissimilarity between the two cluster groups and species contributions to that dissimilarity.

The relationships within and between the biological and environmental variables in Chavara transect during November 2013 and May 2014 were analysed by RDA (Fig. 5). In Redundancy Analysis, the triplot, exhibited that the relative directions of biological variable arrows had linear correlation among them. The arrows pointing in the opposite directions were predicted to have variables with a high negative correlation and arrows pointing in the same direction correspond to variables that are predicted to have a high positive correlation. In triplot, angle between the arrows of the environmental variables were useful to approximate the correlations among environmental variables in the scaling that are focused on biological correlations. Salinity and temperature oriented in the same direction indicating both were in a positive relationship to each other. The nitrate concentration in opposite direction indicated inverse relationship with temperature and salinity. The zooplankton density, chlorophyll a and species of *Acartia danae*, *Acartia erythraea*, *Oithona similis*, *Oithona spinirostris*, *Oithona rigida*, *Centropages tenuiremis*, *Temora turbinata*, *Centropages orsini* and *Paracalanus parvus* oriented to right hand direction which represents positive relationship to one another.

Low concentrations of nitrate, warm temperature and high salinity was found during May represented oligotrophic or low productivity in Chavara related to less production; cool, nutrient rich water column indicates upwelling signatures during November. Moreover, the upwelling indicator species Temora turbinata (Gowsami and Padmavati, 1996; Jagadeesan *et al*., 2013) was more abundant in the study, which indicated continuation or weakened upwelling of winter cooling during November. The distribution and abundance of copepods species alters the diversity pattern, when single species dominated to total density. The observation of increasing copepod species richness during spring intermonsoon was reported from inshore waters of Western Bay of Bengal (Rakesh *et al*., 2013). In the present study, the high species richness was found in the spring intermonsoon period compared to northeast monsoon period. It is concluded that there is a variation in the zooplankton abundance and copepod species diversity of Chavara Coast, due to the influence of seasonally varying hydrography of that environment.

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