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Copepod community structure during upwelling and non-upwelling seasons in coastal waters off Cochin, southwest coast of India

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Abstract

Vypeen, an island of Cochin estuarine system, acts as the spawning site of several marine and estuarine fishes. We assumed that, physical process (upwelling) make changes in hydrography and the production of chlorophyll *a* in coastal waters off Vypeen. These alterations can influence the zooplankton abundance and copepod community structure in that area. For justifying this hypothesis, samples were collected from Vypeen at 10 m and 30 m locations during January (pre-southwest monsoon), August (late-southwest monsoon) and November (post-southwest monsoon) 2014. During August, subsurface water column was cool, nutrient rich and less oxygenated (signatures of upwelling) than in November and January. Maximum concentrations of nitrate and chlorophyll *a* were recorded during August. In the present study, 15 zooplankton groups were recorded; of which copepods were the most predominant group (73%–90%). Copepod density in the present study ranged between 527.2 ind./m^3 and 5 139.2 ind./m^3. Totally, 37 copepods species were reported in present study and copepod species richness was higher during January. The abundance of zooplankton and copepods was high in August during late-southwest monsoon. These variations were closely associated with the coastal upwelling in August and weakening of moderate upwelling in November. In SIMPER analysis, it was found that the copepods species distribution was similar within season and dissimilar between the three seasons. Moreover, the higher abundance of upwelling indicator species *Temora turbinata* was recorded in August, which confirms the signs of seasonal upwelling in Vypeen. The present study emphasized on the influence of hydrographical parameters associated with physical process, in governing the copepod community organization of the Vypeen Island.

Key words: copepods, community, multivariate analysis, monsoon, *Temora turbinata*, upwelling, zooplankton

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1 Introduction

Copepods are the dominant mesozooplankton in the marine environment, especially in the estuaries and coastal regions where they contribute over 80%–90% (Srichandan et al., 2014) of the total zooplankton abundance. Most of the recent literatures that reported on the zooplankton and copepods in the Indian waters with respect to the ocean physics are related to the upwelling (Fernandes and Ramaiah, 2009; Rakhesh et al., 2008, 2006). However, recent literature on the zooplankton and copepod species diversity from Kerala coast (Cleetus et al., 2016; Vineetha et al., 2015; Jeyaraj et al., 2014; Robin et al., 2009) is very limited. Similarly, comparative studies of the copepod community structure during upwelling period with respect to the non-upwelling periods along Southwest coast of India and especially from Kerala are meager (Jagadeesan et al., 2017; Sooria et al., 2015; Vineetha et al., 2015; Varghese and Krishnan, 2009; Madhupratap, 1978; Tranter and Abraham, 1971).

In the southwest coast of India the reversal of the coastal currents and prominent upwelling during the southwest monsoon period, brings dynamic changes (Bhattathiri et al., 1996) in estuaries and coastal waters. This region is also experienced by the winter cooling and the maintenance of weakened upwelling during the northeast monsoon (Smitha et al., 2014). Also, the seasonally varying river flow make changes in hydrography and chlorophyll *a* levels along the Cochin estuary (Shivaprasad et al., 2013). Vypeen is considered as a highly bioproductive coastal area of Cochin Backwaters along southwest coast of India. Copepods were found to be the predominant group among zooplanktons in present study. Considering this importance, the present study was carried out to evaluate the zooplankton distribution and copepod species diversity related to hydrography during upwelling and non-upwelling periods in Vypeen.

2 Materials and methods

2.1 *Study area*

The study area was distributed along the latitudes 9°N and 10°N (southwest coast of India). The Vypeen Island (10 m location–latitude 9.952 83°N and longitude 76.286 1°E; 30 m location–latitude 9.952 78°N and longitude 76.188 8°E) is the transect which selected for the study. This transect is located in Kerala along southwest coast of India. Two locations in Vypeen transect were selected for sampling, one is at 10 m and another one is at 30 m (Fig. 1). A mixed, semidiurnal type tides with a maximum range of about 1 m usually experiences along this coastal area off Cochin Backwaters. Vypeen is a highly bioproductive coastal area of southwest coast of India which is bound by the Arabian Sea on western side and the Cochin Backwaters

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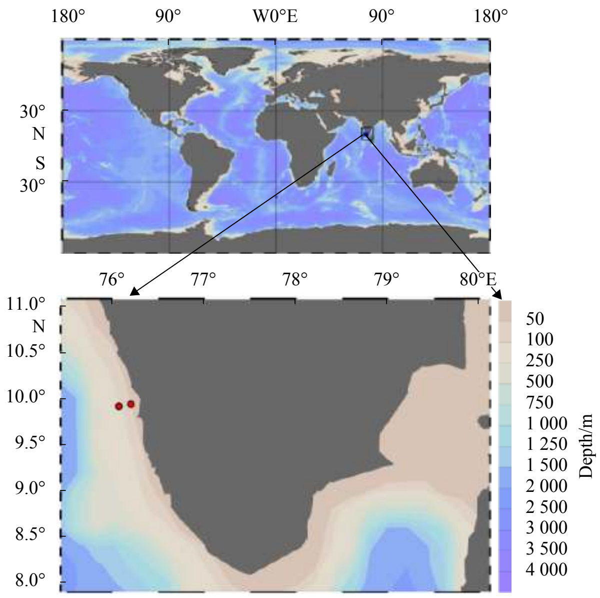

Fig. 1. Map showing the geographical locations of the sampling station.

on eastern side.

2.2 *Sampling and methods*

Samples were collected in three seasons from Vypeen at 10 m and 30 m locations. For the comparison of seasonal changes, sampling was carried out in January 2014 (pre-southwest monsoon), August 2014 (late-southwest monsoon) and November 2014 (post-southwest monsoon). At each location, water samples were collected from the surface (0.5 m) using Niskin sampler (General Oceanics, USA) for the estimation of chlorophyll *a*, nutrients and dissolved oxygen. The vertical distribution of physical parameters such as salinity and temperature were recorded by factory calibrated sensors. Temperature was measured by using a thermometer and salinity by using a calibrated probe, immediately after taking the water sample at each station. The dissolved oxygen in the surface and subsurface waters was measured by Winkler's method (Grasshoff et al., 1983). The total chlorophyll *a* was measured by concentrating 1 L of water samples on Whatman GF/F filters (0.2 μm) and was extracted using 10 mL 90% acetone. The extracted chlorophyll *a* was measured using a Trilogy Turner fluorometer following the standard procedure (UNESCO, 1994). Nitrate concentrations in water were measured by following Grasshoff's method (Grasshoff et al., 1983). 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 samples were transferred into cleaned 0.5 L plastic containers and were fixed in (4%–5%) buffered formalin. The samples were filtered through a 200 μm nylon sieve in the laboratory and excess water in the samples was removed using blotting papers.

Zooplankton samples were evaluated qualitatively and quantitatively in the laboratory by following the standard procedures of Postel et al. (2000). The zooplankton sample was split into four sub-samples (25%) using a Folsom's plankton sample splitter (Sell and Evans, 1982). One of these sub-samples (25%) was sorted under a stereozoom microscope (Model–Mastic DMW–143–FBGG) and taxonomic group level abundance was estimated (Postel et al., 2000). Among various taxonomic groups, copepods were analyzed thoroughly and their species were identified using standard keys (Kasturirangan, 1963; Conway et al., 2003). The abundance of copepods was expressed as ind./m^3. Zooplankton diversity indices-species diversity index (H), species richness (d), evenness index (J') were evaluated by applying the formulas of Shannon and Weaver (1963), Margalef (1968) and Pielou (1969) respectively.

2.3 *Statistical analysis*

In order to compare the hydrography and the zooplankton characteristics in Vypeen, univariate and multivariate analysis was done. Based on biological parameters, sampling locations were segregated using hierarchical agglomerative method of cluster analysis. The data of copepods species abundance were initially $\log_{10}(X+1)$ transformed for normalizing the differences in numerical abundance (Clarke and Warwick, 2001). The Bray-Curtis similarity matrix was used for the spatial grouping of locations in different seasonal collections. In addition to cluster analysis, similarity profile (SIMPROF) permutation test was also performed to identify significant assemblages of stations ($p<0.01$) (Clarke and Gorley, 2006). The relationship between copepod species and some essential environmental variables were evaluated by using RDA (CANOCO 4.5). Samples were displayed by points and species and quantitative environmental variables were shown by arrow in RDA triplots.

3 Results and discussion

3.1 *Hydrography and chlorophyll a*

The temporal distribution of surface temperature showed 23.4°C to 31.5°C variations between January, August and November (Table 1). During January the water column was little warmer (31.5°C and 30.9°C at 10 m and 30 m locations respectively), than the months of August and November. Surface salinity

Table 1. Distribution of the physicochemical parameters in the Vypeen transect during January, August and November 2014

Parameters	Depth	Jan. 2014		Aug. 2014		Nov. 2014	
		10 m	30 m	10 m	30 m	10 m	30 m
Salinity	S	34.43	34.02	31.06	32.15	33.36	33.98
	B	34.56	34.58	34.61	34.63	34.57	34.58
Temperature/°C	S	31.5	30.9	24.3	25.1	28.9	28.8
	B	28.5	28.6	23.5	23.4	28.1	28.3
Nitrate/μmol·L^{-1}	S	0.24	0.31	5.69	4.91	3.15	3.92
	B	0.64	0.68	11.36	10.35	4.16	4.98
Chlorophyll *a*/mg·m^{-3}	S	1.30	0.40	7.0	8.96	5.36	3.14
	B	1.20	0.38	5.9	6.90	3.02	2.19
Dissolved oxygen/mg·L^{-1}	S	5.56	5.86	6.72	6.65	5.96	5.93
	B	3.56	3.64	0.56	0.59	3.09	3.07

ranged from 31.06 to 34.63 in present study (Table 1). Surface salinity was comparatively less during August, but remarkably subsurface salinity was high compared to January. The high surface water temperature and salinity during the pre-southwest monsoon period (January) along the Arabian Sea has been reported by Madhupratap (1978). During the southwest monsoon period salinity values in coastal waters changes due to the freshwater inputs from the outlets of Cochin Backwaters. In present study, the sea surface temperature and salinity were less in the Vypeen during the late-southwest monsoon period. Similar changes about the salinity and temperature has been reported by Haugen et al. (2002) and Madhupratap (1978) previously from Cochin Backwaters. During the northeast monsoon (November) period the coastal water salinity becomes intermediate between late-southwest monsoon period (August) and pre-southwest monsoon period (January). These observations were accordance with the earlier observations like Madhupratap (1978), Madhupratap et al. (2001) from the South Eastern Arabian Sea.

In general nitrate concentration was two to five folds higher during August compared to January. During August surface nitrate concentrations were 5.69 μmol/L at 10 m and 4.91 μmol/L at 30 m locations (Table 1). The lowest concentration of nitrate was found during January compared to August and November in the present study. The previous investigation by Rajagopalan et al. (1992) has recorded low surface water nitrate concentration during pre-monsoon along southwest coast of India. The highest concentration of dissolved oxygen in surface waters was recorded during August (6.72 mg/L) and the lowest concentration of dissolved oxygen in subsurface waters was found in the same season (August). It indicates the subsurface hypoxia during upwelling period (Table 1). The higher nitrate concentrations, reduced temperature and less oxygenated water in the Arabian Sea may be the result of the coastal upwelling and winter cooling during southwest monsoon, northeast monsoon periods respectively (Gerson et al., 2014).

Generally chlorophyll rich waters were observed in upwelling areas by Bhattathiri et al. (1996) and Rajagopalan et al. (1992). Chlorophyll *a* is regarded as the indirect representation of the phytoplankton production. Chlorophyll *a* concentrations ranged from 0.40 mg/m^3 to 8.96 mg/m^3. The concentration of chlorophyll *a* was very less during January which denotes the low productivity off Vypeen, in the pre-southwest monsoon period during 2014. The maximum chlorophyll *a* concentration was found during August and moderate during November in the present study (Table 1). These observations confirm the upwelling signatures during August (Late-Southwest Monsoon) and the winter cooling due to the weakening of moderate upwelling during November (post-southwest monsoon) in Vypeen.

3.2 *Zooplankton distribution and copepod diversity*

Zooplankton abundances showed significant seasonal variation in present study. A total of 15 zooplankton groups were reported in the present study (Table 2). Density of the zooplankton varied from 660.6 ind./m^3 to 7 001.9 ind./m^3. Zooplankton abundances were higher during August and November, but it was found to be lower during January in Vypeen. Copepod contribution to the total density was high (>80%) in 10 m location compared to the 30 m location. The maximum density of copepod (90%) was found during the late-southwest monsoon period (month of August at 10 m location). Cladocerans contributed (0.9%–23.2%) to the total density of zooplankton; higher density was observed during August and November compared to January. The copepod predators like Chaetognaths, Siphonophores and Hydromedusae density was high during August and November compared to January. The other holoplankton groups found in the total density was Lucifer, Mysids, Thalacians, Appendicularians, but they contributed 1%–2% to the total density of the zooplankton. Three different groups of the meroplankton was found such as polycheate larvae, molluscan larvae, decapod larvae their contribution was found 0.2%–5% to the total density. Variations in abundance of zooplankton and copepods in the Cochin Backwaters during upwelling and non-upwelling seasons have been recorded by Sooria et al. (2015), Vineetha et al. (2015) and Varghese and Krishnan (2009). In the present study, the most abundant group was copepod (⩾80%). The previous studies from Cochin Backwaters showed that copepods were the most predominant group among zooplankton (Vineetha et al., 2015; Madhupratap, 1979). Recently, higher abundance of meso-

Table 2. Zooplankton group wise abundance (ind./m^3) in the three different seasonal collections in Vypeen transect during January, August and November 2014

Groups	Jan. 2014		Aug. 2014		Nov. 2014	
	10 m	30 m	10 m	30 m	10 m	30 m
Medusae	0	0.3	1.82	1.56	0.86	0.79
Siphonophores	3.2	2.4	24.16	57.6	3.12	2.14
Chaetognaths	12.5	9.9	19.2	169.6	7.3	16
Copepods	650.1	525.2	3 211.3	5 139.2	1 667.7	4 179.2
Cladocerans	15.4	5.9	259.2	1 574.4	296.2	1 276.8
Appendicularians	4.5	4.4	41.6	19.2	10.9	3.2
Lucifer	1.3	0.6	6.4	0.1	3.6	0
Mysid	1.8	0.8	0	0	0	0
Thalacians	0	7.1	6.8	1.9	2.1	1.6
Ostracods	1.51	2.0	3.1	0	0	0
Polychaete larvae	0	0	9.6	0	0	3.2
Mollusacan larvae	4.6	0	0	3.2	14.6	3.2
Decapod larvae	22.1	8.9	3.4	3.2	7.3	19.2
Fish eggs	30.1	92.6	0	25.6	18.3	0
Fish larvae	1.1	0.5	0	6.4	14.6	3.2
Total	747.8	660.6	3 586.5	7 001.9	2 046.5	5 508.5

Note: 0 denotes absence.

zooplankton, especially the dominance of copepods, along the southwest coast of India (Alappuzha in Kerala) during the southwest monsoon period governed by coastal upwelling has documented by Jagadeesan et al. (2017).

Copepod density in the present study ranged between 525.2 ind./m³ and 5 139.2 ind./m³ (Table 2). Copepod density was high in 30 m location during August and November compared to the 10 m location. But the differences between 10 m and 30 m locations were comparable. In the present study, altogether 37 species were reported (Table 3). Among these, 21 species belonged to the order Calanoida, 2 species belonged to the order Harpacticoida, 5 species belonged to Cyclopoida order, 8 species belonged to the order Poecilostomatoida and 1 species belonged to the order Monstrilloida. In Calanoida order, 9 families were found such as Calanidae, Eucalanidae, Paracalanidae, Centropagidae, Pseudodiaptomidae, Temoridae, Candaciidae, Pontellidae and Acartiidae. In Harpacticoida order 2 families were found such as Macrosetellidae, Tachidiidae.

Copepod species distribution pattern during August (upwelling period), November (moderate upwelling) and January (non-upwelling period) showed variations. Especially, the abundance of *Temora turbinata*, *Oithona similis*, *Centropages orsini*, *Paracalanus parvus*, *Centropages tenuiremis*, *Corycaeus catus* and *Acartia erythraea* was significantly varied. The abundance of the *Temora turbinata* (upwelling indicator species) was found several folds higher during the late-southwest monsoon period (August) compared to the pre-southwest monsoon and post-southwest monsoon periods (January and November) in the Vypeen transect. Similar observations has been reported during upwelling season along Indian coastal waters by Jagadeesan et al.

Table 3. Spatial distribution of copepod species in the three different seasonal collections in Vypeen transect during January, August, November 2014

Species name	Jan. 2014		Aug. 2014		Nov. 2014	
	10 m	30 m	10 m	30 m	10 m	30 m
Undinula vulgaris	+	+	++	++++	++	++
Pareucalanus elongatus	0	0	0	0	**	0
Paracalanus parvus	+	++	***	***	0	****
Acrocalanus gibber	+	+	+++	0	++	++
Acrocalanus gracilis	++	++	+++	**	+++	***
Acrocalanus longicornis	+	0	0	0	0	0
Centropages orsini	++	++	+++	****	++	+
Centropages furcatus	+	+	0	0	+	++++
Centropages tenuiremis	0	++	+++	***	+	++
Pseudodiaptomus aurivilli	+	0	0	0	0	0
Pseudodiaptomus serricaudatus	0	+	++	++	0	+
Temora turbinata	++	++	****	****	++	++
Temora stylifera	+	+	0	0	0	0
Temora discaudata	+	0	0	++	0	0
Candacia discaudata	+	+	0	0	0	0
Candacia bradyi	++	+	0	0	0	0
Labidocera acuta	++	++	0	++	+	0
Labidocera pectinata	+	+	0	++	+	+
Pontellina plumata	++	+	0	0	0	0
Acartia erythraea	+	++	++	*	**	**
Acartia danae	++	+	++	++	****	****
Macrosetella gracilis	+	+	0	0	0	0
Euterpina acutifrons	++	+	++	+++	+	+
Oithona spinirostris	++	+	0	++	++	0
Oithona plumifera	0	0	0	++	+	0
Oithona rigida	++	+	0	0	0	+
Oithona similis	++	++	****	**	0	0
Oncaea venusta	++	+	++	++	++	+
Corycaeus speciosus	++	++	0	+++	++	0
Corycaeus danae	+	++	0	0	+	0
Corycaeus catus	++	++	++	**	++	++
Corycella gibbula	+	++++	0	0	0	0
Copilia vitrea	0	0	0	++	0	0
Copilia mirabilis	+	0	0	0	0	0
Sapphirina ovatolanceolata	+	+	0	0	0	0
Sapphirina auronitens	0	+	0	0	0	0
Monstrilloids	+	+	0	0	+	0

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

(2017, 2013), Goswami and Padmavati (1996) and Madhupratap et al. (1990). Copepod species richness was high during the month of January and the minimum species richness was reported during the month of August. Shannon diversity of copepods was high in January (10 m location) compared to the months of August and November. Pielous evenness showed noticeable variations between the observations. Maximum evenness was found during the month of August in 30 m location but during the month of January the evenness values were comparable in 10 m and 30 m locations.

3.3 *Cluster analysis and NMDS*

Spatial and temporal similarity of species distribution of the observations from the Vypeen transect (January, August, November 2014) were grouped into three clusters at the similarity level of 65% (Fig. 2a). Cluster 1 included the 10 m and 30 m locations of the month of January. Second cluster included the 10 m and 30 m locations of the month of August and the cluster 3 included the 10 m and 30 m locations of the month of November. It indicated that the classification of the clustering pattern was significant and the species distribution was significantly differed between the clusters. Cluster overlaid NMDS plot shows that 10 m and 30 m locations of the each month was located close to each other represents the similarity (Fig. 2b). But the points which are located far between the months represent the dissimilarity.

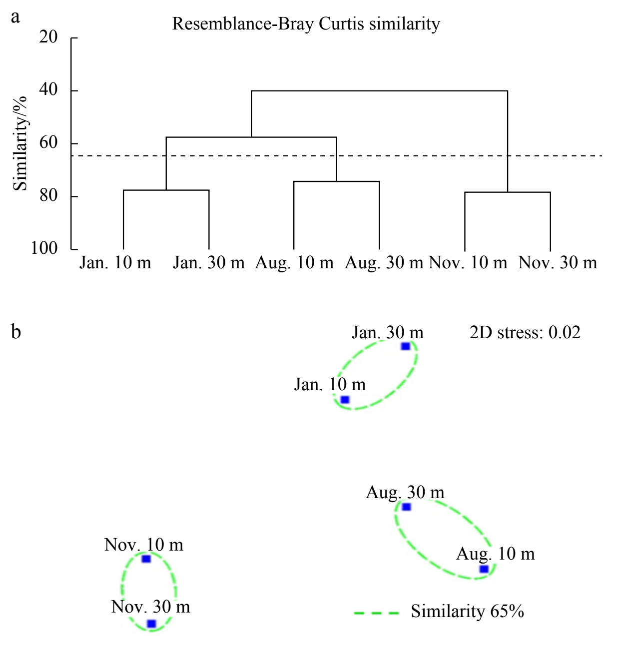

Fig. 2. Bray-curtis similarity index based group average linkage dentrogram of the cluster analysis (a) and cluster overlaid two dimensional NMDS plot of dominant copepod species distribution (b) in Vypeen during January, August and November 2014.

3.4 *SIMPER analysis*

SIMPER analysis (similarity percentage) was performed to find out the species distribution similarity within the cluster and between the clusters. Similarity percentage analysis also represented the dissimilarity of species distribution and provided the information about the dominant species responsible for the dissimilarity. The results of the SIMPER analysis were represented in the Supplementary Information Table S1. Table S1a, b and c provide the information about similarity percentage within the cluster members in Group 1, Group 2 and Group 3, respectively. Table S1d, e and f presents the information about the dissimilarity between Groups 1 and 2, Groups 1 and 3, and Groups 2 and 3 members, respectively. Cluster 1 group members (the locations of 10 m and 30 m during January) showed 61.30% similarity within the cluster. In Cluster 2 (10 m and 30 m locations, during August) the species distribution showed 57.54% similarity within the cluster members. Cluster 3 members (10 m and 30 m locations of November) contributed 60.79% similarity within cluster. The average dissimilarity between Cluster 1 and Cluster 2 was 88.57%. The average dissimilarity between Cluster 1 and Cluster 3 was 91.91%. The average dissimilarity between Cluster 2 and Cluster 3 was 78.99%.

3.5 *Redundancy analysis (RDA)*

RDA was carried out to analyze the relationship between the copepod species and the environmental variables in Vypeen during the pre-southwest monsoon, late-southwest monsoon and post-southwest monsoon periods in 2014 (Fig. 3). Salinity and temperature oriented the same direction indicated that both were positive relationship to each other. The nitrate was oriented opposite to the direction of the temperature and salinity in RDA triplot that indicated its inverse relationship to the temperature and salinity. The zooplankton density, surface and bottom chlorophyll *a* and the species of *Acartia danae*, *Acartia erythraea*, *Oithona similis*, *Centropages tenuiremis*, *Temora turbinata*, *Temora discaudata*, *Centropages orsini* and *Paracalanus parvus* oriented to the right hand direction and that showed the positive relationship to one another.

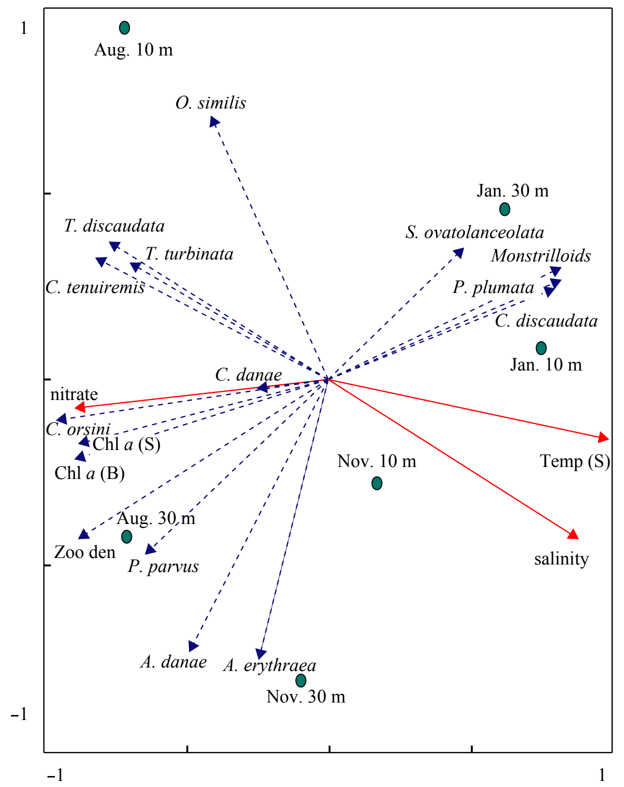

Fig. 3. RDA triplot visualizes the interrelationships within and between the biological and environmental variables in Vypeen. Chl *a* (S) represents chlorophyll *a* at surface, Chl *a* (B) chlorophyll *a* at bottom, Temp (S) temperature at surface, and Zoo den zooplankton density.

Generally, *Oithona similis* occur in the subsurface waters and their abundance shall be less in the surface waters. However, high abundance of *Oithona similis* was found in the surface waters during August (late-southwest monsoon) and November (post-southwest monsoon) respectively in the present study. The similar observation was reported from estuarine waters of Washington by Keister and Tuttle (2013). Their investigations suggested that the *Oithona* may be migrated to the surface layers due to subsurface hypoxia during upwelling seasons. Lowest species richness and highest evenness values were found in the late-southwest monsoon period compared to non-upwelling periods. Similar observation of decreasing copepod species diversity, when one or two species dominated to the total density, during southwest monsoon period was reported from upwelling area along the central west coast of India (Madhupratap et al., 1990).

4 Conclusions

Results of community structure of copepods in coastal waters off Vypeen revealed that distribution and abundance of the copepod species were differed between the seasonal observations associated with physical processes. During August, water column was cool, nutrient rich and less oxygenated (signatures of upwelling) and high in chlorophyll *a* than in November and January. The abundance of zooplankton and copepods was high in August during late-southwest monsoon. High abundance of *Temora turbinata* reported in the study, confirms upwelling during southwest monsoon. These variations were closely associated with the coastal upwelling in August and weakening of moderate upwelling in November.

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References

Bhattathiri P M A, Pant A, Sawant S, et al. 1996. Phytoplankton production and chlorophyll distribution in the eastern and central Arabian Sea in 1994–1995. Current Science, 71(11): 857–862

Clarke K R, Gorley R N, 2006. PRIMER V6: User manual/tutorial. Plymouth: PRIMER-E Ltd., Plymouth Marine Laboratory

Clarke K R, Warwick R M. 2001. Changes in marine communities: An approach to statistical analysis and interpretation. Plymouth: PRIMER-E Ltd, Plymouth Marine Laboratory

Cleetus R I, Asha C V, Suson P S, et al. 2016. Mesozooplankton abundance and community structure in Vembanad-kol wetland ecosystem, Kerala, India. Indian Journal of Geo-Marine Sciences, 45(4): 533–545

Conway D V P, White R G, Hugues-Dit-Ciles J, et al. 2003. Guide to the coastal and surface zooplankton of the south western Indian Ocean. Occasional Publication No. 15. Defra, UK: Marine Biological Association of the United Kingdom

Fernandes V, Ramaiah N. 2009. Mesozooplankton community in the Bay of Bengal (India): spatial variability during the summer monsoon. Aquatic Ecology, 43(4): 951–963, doi: 10.1007/s10452-008-9209-4

Gerson V J, Madhu N V, Jyothibabu R, et al. 2014. Oscillating environmental responses of the eastern Arabian Sea. Indian Journal of Geo-Marine Sciences, 43(1): 67–75

Goswami S C, Padmavati G. 1996. Zooplankton production, composition and diversity in the coastal waters of Goa. Indian Journal of Geo-Marine Sciences, 25(2): 91–97

Grasshoff K, Ehrhardt M, Kremling K. 1983. Methods of Seawater Analysis. Weinheim: Verlag Chemie, 89–224

Haugen V E, Johannessen O M, Evensen E. 2002. Mesoscale modeling study of the oceanographic conditions off the Southwest coast of India. Journal of Earth System Science, 111(3): 321–337, doi: 10.1007/BF02701978

Jagadeesan L, Jyothibabu R, Anjusha A, et al. 2013. Ocean currents structuring the mesozooplankton in the Gulf of Mannar and the Palk Bay, Southeast coast of India. Progress in Oceanography, 110: 27–48, doi: 10.1016/j.pocean.2012.12.002

Jagadeesan L, Jyothibabu R, Arunpandi N, et al. 2017. Dominance of coastal upwelling over Mud Bank in shaping the mesozooplankton along the southwest coast of India during the Southwest Monsoon. Progress in Oceanography, 156: 252–275, doi: 10.1016/j.pocean.2017.07.004

Jeyaraj N, Joseph S, Arun, et al. 2014. Distribution and abundance of zooplankton in estuarine regions along the northern Kerala, Southwest coast of India. Ecologia, 4(2): 26–43, doi: 10.3923/ecologia.2014.26.43

Kasturirangan L R. 1963. A key for the identification of the more common planktonic copepoda of Indian coastal waters. In: Panikkar N K, ed. Indian National Committee on Oceanic Research. New Delhi: Council of Scientific and Industrial Research, 1–87

Keister J E, Tuttle L B. 2013. Effects of bottom-layer hypoxia on spatial distributions and community structure of mesozooplankton in a sub-estuary of Puget Sound, Washington, U.S.A. Limnology and Oceanography, 58(2): 667–680, doi: 10.4319/lo.2013.58.2.0667

Madhupratap M. 1978. Studies on the ecology of zooplankton of Cochin Backwaters. Mahasagar-Bulletin of the National Institute of Oceanography, 11: 45–46

Madhupratap M. 1979. Distribution, community structure and species succession of copepods from Cochin Backwaters. Indian Journal of Geo-Marine Sciences, 8(1): 1–8

Madhupratap M, Gopalakrishnan T C, Haridas P, et al. 2001. Mesozooplankton biomass, composition and distribution in the Arabian Sea during the Fall Intermonsoon: Implications of oxygen gradients. Deep Sea Research Part II: Topical Studies in Oceanography, 48(6–7): 1345–1368

Madhupratap M, Nair S R S, Haridas P, et al. 1990. Response of zooplankton to physical changes in the environment: Coastal upwelling along the central west coast of India. Journal of Coastal Research, 6(2): 413–426

Margalef D R. 1968. Perspectives in Ecological Theory. Chicago: University of Chicago Press

Pielou E C. 1969. Introduction to Mathematical Ecology. New York: Wiley-Interscience

Postel L, Fock H, Hagen W. 2000. Biomass and abundance. In: Harris R P, Wiebe P H, Lenz J, et al., eds. ICES Zooplankton Methodology Manual. London: Academic Press, 193–213

Rajagopalan M S, Thomas P A, Mathew K J, et al. 1992. Productivity of the Arabian Sea along the Southwest coast of India. Bulletin of the Central Marine Fisheries Research Institute, 45: 9–37

Rakhesh M, Raman A V, Kalavati C, et al. 2008. Zooplankton community structure across an eddy-generated upwelling band close to a tropical bay-mangrove ecosystem. Marine Biology, 154(6): 953–972, doi: 10.1007/s00227-008-0991-2

Rakhesh M, Raman A V, Sudarsan D. 2006. Discriminating zooplankton assemblages in neritic and oceanic waters: A case for the northeast coast of India, Bay of Bengal. Marine Environmental Research, 61(1): 93–109, doi: 10.1016/j.marenvres.2005.06.002

Robin R S, Srinivasan M, Chandrasekar K. 2009. Distribution of zooplankton from Arabian Sea, along Southern Kerala (Southwest coast of India) during the cruise. Current Research Journal of Biological Sciences, 1(3): 155–159

Sell D W, Evans M S. 1982. A statistical analysis of subsampling and an evaluation of the Folsom plankton splitter. Hydrobiologia, 94(3): 223–230, doi: 10.1007/BF00016403

Shannon C E, Weaver W. 1963. The Mathematical Theory of Communication. Urbana, Illinois: University of Illinois Press, 1–117

Shivaprasad A, Vinita J, Revichandran C, et al. 2013. Seasonal stratification and property distributions in a tropical estuary (Cochin estuary, West coast, India). Hydrology Earth System Science, 17(1): 187–199, doi: 10.5194/hess-17-187-2013

Smitha A, Joseph K A, Jayaram C, et al. 2014. Upwelling in the Southeastern Arabian Sea as evidenced by Ekman mass transport using wind observations from OCEANSAT-II scatterometer. Indian Journal of Geo-Marine Sciences, 43(1): 111–116

Sooria P M, Jyothibabu R, Anjusha A, et al. 2015. Plankton food web and its seasonal dynamics in a large monsoonal estuary (Cochin Backwaters, India)-significance of mesohaline region. Environmental Monitoring and Assessment, 187(7): 427, doi: 10.1007/s10661-015-4656-6

Srichandan S, Panda C R, Rout N C. 2014. Summer distribution of zooplankton in coastal waters of Odisha, East coast of India. International Journal of Oceanography and Marine Ecological System, 3(1): 9–25, doi: 10.3923/ijomes.2014.9.25

Tranter D J, Abraham S. 1971. Coexistence of species of Acartiidae (Copepoda) in the Cochin Backwater, a monsoonal estuarine lagoon. Marine Biology, 11(3): 222–241, doi: 10.1007/BF00401271

UNESCO. 1994. Protocols for the Joint Global Ocean Flux Study (JGOFS). Core Measurements, IOC Manuals and Guides, Vol 29. Paris: UNESCO, 170

Varghese M, Krishnan L. 2009. Distribution of zooplankton in selected centres of Cochin backwaters, Kerala. Journal of the Marine Biological Association of India, 51(2): 194–198

Vineetha G, Madhu N V, Kusum K K, et al. 2015. Seasonal dynamics of the copepod community in a tropical monsoonal estuary and the role of sex ratio in their abundance pattern. Zoological Studies, 54: 54, doi: 10.1186/s40555-015-0131-x

Supplementary information:

Table S1. Result of SIMPER analysis represents the similarity within and between the clusters in Vypeen during January, August, November 2014.

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