Tropical Ecology **56**(3): 311-322, 2015 ISSN 0564-3295

www.tropecol.com

Zooplankton community structure in the nearshore waters of central west coast of India

SOCORRINHA D'COSTA* & I. K. PAI

Department of Zoology, Goa University, Goa 403206, India

Abstract: Environmental conditions and zooplankton populations were studied in the nearshore waters of Colva and Karwar, along the central west coast of India to assess the spatial and temporal variations in zooplankton composition. Environmental variables (temperature, dissolved oxygen [DO], nitrates, phosphates, turbidity, total dissolved solids [TDS]) and zooplankton taxonomic abundances were studied on a monthly basis from August 2011 to May 2012. The physicochemical data was subjected to principal component analysis (PCA) to test which variables contributed significantly to changes in water conditions. The relationship between environmental variables and zooplankton density was tested using canonical correspondence analyses. Overall, zooplankton species diversity and richness were higher at Colva (35 taxa) than at Karwar (25 taxa). Variation in water quality was attributed to anthropogenic activities and freshwater input in Karwar and seasonal effects in Colva. For Karwar and Colva the primary determinants of zooplankton community structure were turbidity and salinity. Copepods dominated Colva waters throughout the study period, though their species composition exhibited seasonal variations. At Karwar, decapods were prominent during monsoon, while copepods were dominant for the rest of the year. The present study recorded the occurrence of larvae of commercially important *Penaeus* sp. very close to the shore in Karwar, suggesting that, the turbid waters of Karwar may serve as *Penaeus* breeding grounds.

Resumen: Se estudiaron las condiciones ambientalesy las poblaciones de zooplancton en las aguas costerasde Colvay Karwar alo largo dela costa centro occidental de la India con el fin de evaluarlas variaciones espaciales y temporales en la composición del zooplancton. Desdeagosto de 2011 hasta mayo de 2012 se examinaron mensualmente variables ambientales (temperatura, oxígeno disuelto [OD], nitratos, fosfatos, turbidez, sólidos disueltos totales [TDS]) así como las abundancias taxonómicasdel zooplancton. Los datos fisicoquímicos fueron sometidos a un análisis de componentes principalespara averiguar cuáles variables contribuyen significativamentea los cambios en las condiciones del agua. Larelaciónentre variables ambientales y la densidad del zooplanctonfue examinada por medio de análisis canónicos de correspondencia. En general, la diversidady la riqueza deespecies de zooplanctonfueron mayores enColva (35 taxa) que en Karwar (25 taxa). La variación dela calidaddel agua fue atribuidaa las actividadesantropogénicasy a la entrada de agua dulce en Karwar, y a efectos estacionalesen Colva. En Karwary Colvalos determinantes primarios de la estructura de la comunidad zooplanctónicafueron la turbidezy la salinidad. Los copépodos dominaronlas aguas en Colvadurante todo el periodo de estudio, si bien su composición de especies exhibióvariaciones estacionales. EnKarwar, los decápodos fueron prominentes durante el monzón, mientras que los copépodos fueron dominantes en el resto del año. En este estudiose registrólapresenciade larvasde laespecie comercial mente importante *Penaeus* sp. muy cerca de la costaen Karwar, lo que sugiere que las aguas turbias de Karwar puede servir como terrenos de reproducción de *Penaeus*.

Corresponding Author; e-mail: succorinad@yahoo.com

Resumo: Foram estudadas as condições ambientais e as populações de zooplâncton nas águas costeiras de Colva e Karwar, ao longo da zona central da costa oeste da Índia para avaliar as variações espaciais e temporais na composição do zooplâncton. As variáveis ambientais (temperatura, oxigénio dissolvido (DO), nitratos, fosfatos, turbidez, sólidos totais dissolvidos [TDS]) e abundância taxonómicade zooplâncton foram estudadas numa base mensal a partir de agosto de 2011 a maio de 2012. Os dados físico-químicos foram submetidos a análise de componentes principais (PCA), para testar quais as variáveis que contribuiram significativa mente para as alterações das condições da água. A relação entre as variáveis ambientais ea densidade de zooplâncton foi testada usando uma análise de correspondências canónicas. No geral, a diversidade e riqueza de espécies de zooplâncton foram maiores em Colva (35 táxons) do que em Karwar (25 táxons). A variação da qualidade da água foi atribuída a atividades antrópicas e à entrada de água doce em Karwar e aos efeitos sazonais em Colva. Para Karwar e Colva, os principais determinantes da estrutura da comunidade de zooplâncton foram a turbidez e a salinidade. Os Copépodes dominavam as águas em Colva durante todo o período do estudo, embora a sua composição de espécies exibissevariações sazonais. Em Karwar, os decápodes foram proeminentes durante a monção, enquanto os copépodes foram dominantes durante o resto do ano. O presente estudo registou a ocorrência de larvas de *Penaeus* sp de importância comercial muito perto da costa, em Karwar, sugerindo que as águas turvas de Karwar podem servir como áreas de criação de *Penaeus*.

Key words: CCA, copepods, decapods, PCA, *Penaeus* sp., turbidity.

Introduction

Nearshore coastal waters are highly dynamic and provide unique habitat for a variety of organisms often serving as an important spawning and nursery grounds for prawn and finfishes (Gajbhiye *et al.* 1994). Of late, the quality of nearshore coastal waters is deteriorating due to industrial and municipal wastes, storm waters, agricultural runoff, and enhanced anthropogenic activities (EPA 1998). Many coastal areas are reported to be damaged by pollution, significantly affecting commercial coastal fisheries (Bonsdorff *et al.* 1997; Hernandez *et al.* 1998).

The coastal waters along the west coast of India are over exploited for marine resources. They are also used for dumping industrial effluents and domestic sewage (Kumar *et al.* 2004; Robin *et al.* 2012). In addition, they are also affected by natural activities such as tides, waves, winds, and hydrography (Hedge *et al.* 2008). As the coastal areas are thickly populated and have many tourism activities, major threats to these waters are domestic and municipal wastes, sewage sludge, eutrophication, and algal blooms. High concentration of sewage causes reduction in the oxygen content of water, subjecting the aquatic life to anoxic conditions (Islam & Tanaka 2004). Increased nutrient loading in coastal waters leads to increased phytoplankton growth which in turn results in algal blooms (Cloern 2001). This above situation affects dissolved oxygen (DO) concentrations and light penetration, disrupting the aquatic life. Zooplankton are drifting or floating organisms, inhabiting the waters. They occupy an important position in the marine food chain as a connecting link between producers and consumers. They have a short life span and are sensitive organisms, hence are used as bioindicators of water quality (Goswami 2004).

The present study was undertaken in the nearshore waters of Karwar and Colva along the central west coast of India. Karwar, situated in the state of Karnataka, is one of the important coastal towns along the central west coast of India. It has a natural harbor serving both commercial and defense vessels. Due to urbanization, human habitation, and unplanned development around the beach, littering on the beach is prominent with no adequate mechanism for collection and disposal of garbage. Added to the above, inadequate sanitation measures, port activities, effluent discharge from domestic and industries, tanker ballast from shipping traffic, and dumping of fish waste pollute the waters (KSCZMA 2008). As the Kali River joins the Arabian Sea near this beach, dilution of the water and lowering of its conductivity occurs. The town of Colva, situated in south Goa, is a wellknown tourist destination. There are anthropogenic and fishing activities on and off the coast of Colva beach throughout the year and a creek where all types of wastes are dumped also finds its way into the sea.

Studies conducted by Iyyapparajanarasimapallavan *et al*. (2013) and Naomi (1986) along the west coast of India have reported good standing stocks of zooplankton in these waters. Larvae of commercially important prawns are also reported to be present for a longer period of time in the nearshore waters of Karwar (Nair & Paulinose 1980). Besides prawns, Noble (1972) also reported that schools of mackerels coming close to the shore contribute to the commercial fishery at Karwar. Goswami & Padmavati (1996) worked on zooplankton in the coastal waters of Goa and recorded a total of 58 species of pelagic copepods belonging to calanoids (42), cyclopoids (12), and harpacticoids (4). Colva beach was reported to have an imminent potential for the development of molluscan fishery (NIO 1972). A preliminary study was conducted at both these study sites, which revealed that copepods were the dominant group in summer and post-monsoon (D'Costa & Pai 2010).

Despite the importance of nearshore waters, there is a lacuna in the knowledge about zooplankton composition and variation in these waters relative to oceans, estuaries, and freshwater systems (Bere 2014; Sharma 2009; Sharma 2011).

As coastal waters of Karwar and Colva are constantly subjected to anthropogenic activities, we hypothesized that, these waters would show high environmental variation in general and physico-chemical properties in particular. In addition, because Karwar waters get diluted from the freshwater input of Kali River, the zooplankton taxa occurring in this region would be different from those existing in the waters of Colva. The present work was undertaken to characterize zooplankton community structure seasonally in the nearshore waters of Karwar and Colva and to identify potential environmental variables influencing zooplankton composition.

Materials and methods

Study area

Karwar beach and Colva beach occur along the west coast of India (Fig. 1) and are separated by a distance of 78 km. Both beaches receive rainfall from the south west monsoon winds. Based on the variations in their hydrographic features, both these coastal systems can be divided into four seasons: monsoon (June - September), post-monsoon (October - November), winter (December-February), and summer (March - May). The coastline of Karwar is arc-shaped. The average depth of the nearshore waters is 10 m. It is one of the busy fishing ports of India with six landing centres. Noble (1980) reported the importance of these waters in relation to local Indian mackerel fishery. The nearshore waters of Colva have an average depth of 11 m. It is one of the important fishing villages and fish landing centres of Goa and a popular tourist destination.

Sampling design and analyses

Sampling was carried out monthly from August 2011 to May 2012 at three points that were 50 m apart, in the nearshore waters of each location Colva and Karwar. Water and zooplankton samples were collected from the surface waters. During each sampling event, water for testing electrical conductivity (EC), pH, total alkalinity, turbidity, total dissolved solids (TDS), nitrates, and phosphates was collected in acid washed bottles. Water for dissolved oxygen (DO), biochemical oxygen demand (BOD_5), and chlorophyll estimation was collected in amber colored bottles. Surface water temperatures were recorded with a centigrade thermometer. Zooplankton samples from both the sites were collected manually by horizontal haul method using a plankton net (250 µm mesh, 29 cm diameter) and were then fixed in 4 % buffered formalin solution. As a part of the physico-chemical parameter analyses, conductivity, pH, total alkalinity, turbidity, total dissolved solids, dissolved oxygen, biochemical oxygen demand, nitrates, and phosphates were analyzed by following the protocols as specified in APHA (1985) and Trivedy & Goel (1987). Chlorophyll concentration of water sample was determined according to SAPWA (1999).

Zooplankton density (# m^{-3}) was calculated by using the method of Perry (2003) to estimate the volume of water passing through the plankton net during sampling. Whole samples of zooplankton were sorted and identified to the species level using a Stereozoom Leica EZ4D and taxonomic keys provided by Conway *et al.* (2003) and Kasturirangan (1963).

Statistical analyses

The monthly data obtained for physico-chemical parameters were subjected to principal

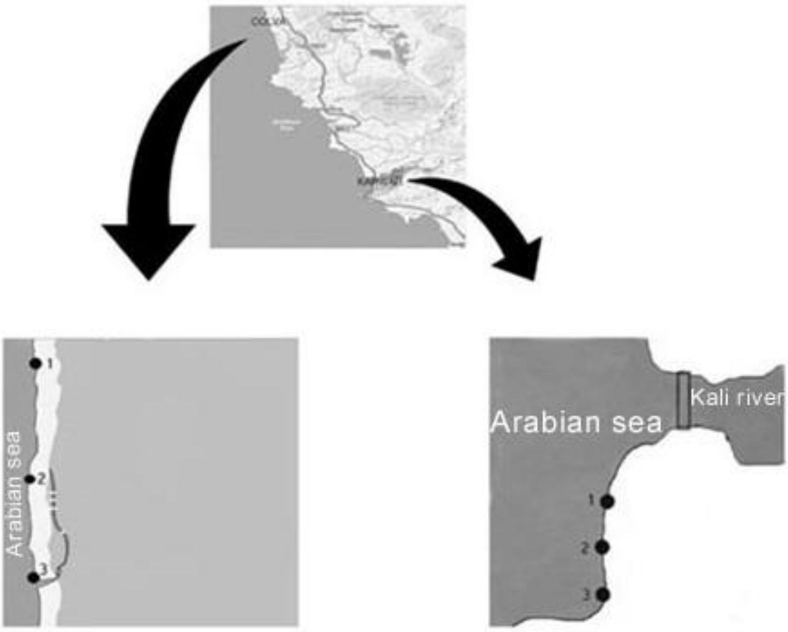

Fig. 1. Map of Central west coast of India showing the stations in Colva and Karwar.

Table 1. Environmental variables of Karwar and Colva coastal waters (August 2011 - May 2012) (Mean ± S.D.).

Factors	Karwar	Colva
Temperature (°C)	29.3 ± 2.1	28.8 ± 1.7
Dissolved oxygen (mg l^{-1})	4.1 ± 0.9	3.9 ± 0.7
Biochemical oxygen demand (mg l^{-1})	3.45 ± 3.0	4.37 ± 3.4
Nitrates (µg l^{-1})	0.4 ± 0.3	1.7 ± 1.4
Phosphates (µg l^{-1})	0.8 ± 1.2	1.75 ± 1.9
Turbidity (NTU)	35.8 ± 20.9	25.8 ± 9.2
Electrical conductivity (µs cm^{-1})	33210 ± 8727	39720 ± 8982
Total dissolved solids (mg l^{-1})	23920 ± 11970	35290 ± 15956
Salinity	20.87 ± 3.1	25.4 ± 4.2

component analysis to determine which variables contributed significantly to the variation in water quality. Monthly data of the three points at each location were averaged to obtain a final monthly reading. The relationship between environmental variables (turbidity, salinity, TDS, DO) and zooplankton species density was tested by canonical correspondence analysis (CCA). Turbidity, salinity, and TDS were selected for evaluation with CCA because the values for these variables differed considerably between sites or seasonally and DO was selected as oxygen is an important factor for living organisms. Both the tests were carried out using XLSTAT (AddinSoft Inc.) software. The data obtained from physico-chemical analyses and zooplankton density data were log transformed log(x+1) before the analysis. The interpretation of each PC axis was determined on the basis of the factor loadings of the variables as well as the monthly variations of each score. Species diversity indices for monthly data were calculated using Shannon-Weiner index (Pielou 1975; Margalef 1968).

Results

Environmental variables

Table 1 shows the mean values for environmental variables measured in Karwar and Colva. Turbidity during monsoon was higher in Karwar (71 NTU ± 13.44) than in Colva (39 NTU ± 1.41). The electrical conductivity differed between Karwar and Colva. Throughout the study period, it was relatively higher in Colva (39,720 µs cm^{-1} ± 8982)

Table 2. Principal component loadings, eigenvalues and percent variance computed for the coastal waters of Karwar.

	PC1	PC2	PC3	PC4
Temperature	-0.776	0.118	0.315	0.340
pH	-0.651	-0.443	-0.450	0.264
Turbidity	-0.091	0.966	0.017	-0.075
Electrical conductivity	-0.329	-0.788	0.188	-0.134
Nitrates	0.414	-0.084	0.354	0.759
Phosphates	0.652	0.034	0.706	0.171
Chl	0.835	0.269	-0.307	-0.032
Alkalinity	-0.766	0.240	-0.075	-0.007
Dissolved oxygen	-0.625	-0.004	0.454	-0.097
Biochemical oxygen demand	-0.077	-0.055	0.679	-0.485
Total dissolved solids	0.751	-0.536	-0.075	-0.157
Eigenvalue	3.983	2.192	1.736	1.085
Variability %	36.211	19.927	15.779	9.800
Cumulative %	36.211	56.137	71.917	81.778

Table 3. Principal component loadings, eigenvalues and percent variance computed for the coastal waters of Colva.

	PC1	PC2	PC3
Temperature	0.592	-0.691	0.063
pH	0.885	0.323	0.200
Turbidity	0.672	0.049	-0.661
Electrical conductivity	0.922	-0.010	0.326
Nitrates	-0.832	-0.222	0.382
Phosphates	-0.774	-0.111	-0.467
Chl	-0.346	0.783	0.396
Alkalinity	0.914	-0.233	-0.050
Dissolved oxygen	0.299	0.848	-0.015
Biochemical oxygen demand	-0.111	-0.775	-0.113
Total dissolved solids	0.068	-0.394	0.886
Eigenvalue	4.787	2.786	1.908
Variability %	43.515	25.332	17.341
Cumulative %	43.515	68.846	86.187

than in Karwar (33,210 µs cm^{-1} ± 872). Total dissolved solids were higher in Karwar during monsoon; while in Colva it was high during post-monsoon.

PCA analysis of environmental measures at Karwar resulted in 4 significant PCs (eigenvalues > 1) that explained 81.7 % of the cumulative variance in the data (Table 2). PC1 accounted for 36.2 % of the total variance because of a strong positive loading of TDS. The months of April and May had high positive scores for PC1. PC2 accounted for 19.9 % of the total variance with strong positive loading of turbidity and strong negative loading of electrical conductivity. August and September had strong positive scores with PC2. PC3 accounted for 15.7 % of the total variance with moderately positive loadings of phosphates and BOD. December, January and March had positive scores with PC3.

PCA analysis of environmental measures at Colva resulted in 3 significant PCs (eigenvalues > 1) that explained 86.19 % of the cumulative variance in the data (Table 3). PC1 accounted for 43.52 % of the total variance because of strong positive loadings of electrical conductivity, alkalinity and pH, and strong negative loadings of nitrates and phosphates. Additionally, the months of September, October, March, and April had strong positive scores with PC1. PC2 accounted for 25 % of the total variance with strong positive PC loadings of DO and chlorophyll and strong negative loadings of BOD and temperature. December, February, and May had strong positive scores with PC2. PC3 accounted for 17 % of the total variance with a strong positive loading of TDS, and weak negative loadings of BOD, DO, and alkalinity. August had strong positive score with PC3.

In Karwar waters, zooplankton collected belonged to 29 taxa including two cladoceran and 27 copepod species. Colva was more diverse with 35 taxa of zooplankton, including two cladoceran and 33 copepod species. In addition, decapods, ostracods, chaetognatha, appendicularians, polychaete, amphipods, mysids, isopods, cumacea, caridae, balanus and copepod nauplii were observed at both the sites. Monthly variations in

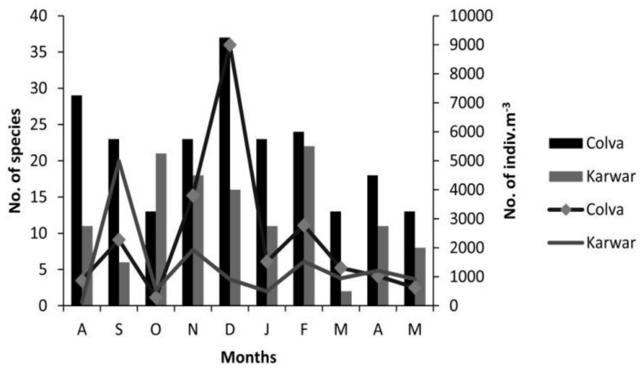

Fig. 2. Monthly variation in zooplankton density and diversity at study sites.

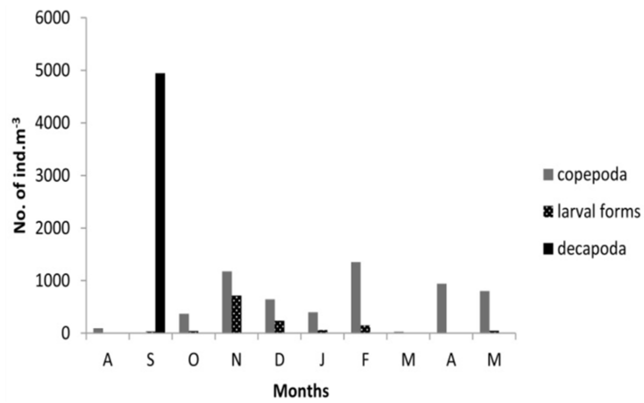

Fig. 3. Monthly variation in major zooplankton groups in the nearshore waters of Karwar.

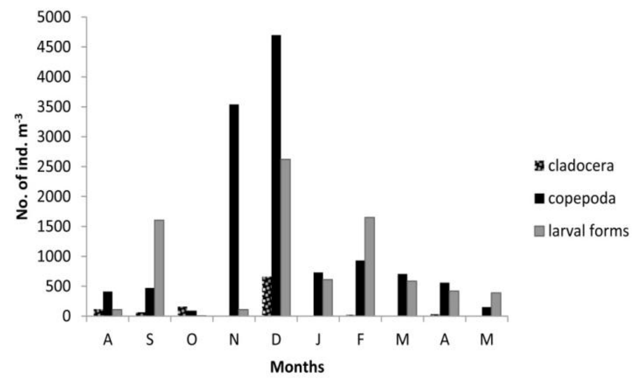

Fig. 4. Monthly variation of major zooplankton groups in the nearshore waters of Colva.

zooplankton diversity and density at both the study sites are depicted in Fig. 2. Figs. 3 and 4 show the variations in major zooplankton groups in Karwar and Colva, respectively. Zooplankton diversity (Shannon-Wiener, H'; species richness, SR) was relatively low in Karwar (H' = 1.55; SR = 12.4) compared to Colva (H' = 2.18; SR = 19.5). Species evenness was low for both study locations (Karwar J' = 0.6, Colva J' = 0.7).

In Karwar, zooplankton taxa that contributed more than 1 % of total abundance were *Penaeus* sp. (37.7 %), *Microsetella norvegica* (17.4 %), *Oithona* spp. (10 %), Gammarid amphipods (8.9 %), copepod nauplii (4 %), *Pseudodiaptomus serricaudatus* (3.9 %), *Canthocalanus pauper* (2.4 %), and *Paracalanus parvus* (2.2 %). Others contributed 13.5 % of the total abundance. *Penaeus* sp. occurred during August and September, while *Evadne tergestina* and *Penilia avirostris* were seen in October. Copepods dominated from November to May. The maximum number of copepod nauplii was recorded during November - December.

In Colva, zooplankton taxa contributing more than 1 % were copepod nauplii (24.8 %), *Oithona* spp. (11.3 %), *Corycaeus* sp.(10 %), polychaete larvae (6.2 %), *Calocalanus pavo* (5.9 %), *Eucalanus* sp. (5.6 %), Appendicularians (4.1 %), *Paracalanus parvus* (3.8 %), *Centropages furcatus* (3.3 %), *Evadne tergestina* (2.4 %), *Penilia avirostris* (2.0 %), *Temora turbinata* (1.7 %), *Oncaea* sp. (1.7 %), and ostracods (1.5 %). The remaining taxa together contributed 15.7 % to the total abundance of zooplankton. Cladocerans were prominent during September and December, while copepods dominated the rest of the year. Amongst the calanoids, *Calocalanus pavo* out-numbered others during monsoon, *Eucalanus* spp. dominated during post - monsoon and *Centropages furcatus* were abundant in winter. *Paracalanus parvus* were present in maximum number during summer. Among the cyclopoids, *Oithona plumifera* were present throughout the year. *Corycaeus* sp. were recorded only during December. Larval forms were observed throughout the study period. In Colva, *Oithona* spp. occurred throughout the year. While in Karwar, such a keystone species was not observed.

Canonical correspondence analysis related zooplankton abundance with four selected environmental variables. It accounted for 87.1 % of variance in Karwar (Fig. 5 a&b). *Penaeus* sp. was the only species that was associated with elevated turbidity and relatively low salinity and conductivity. *Oithona* spp. and *Paracalanus parvus* were associated with relatively high salinity. *Microsetella norvegica* and *Pseudodiaptomus serricaudatus* were found to be in high abundance where there were high levels of total dissolved solids. In Colva, CCA accounted for 75.4 % of variance (Fig. 6 a&b). *Penilia avirostris* and ostra-

Table 4. Systematic list of zooplankton observed at study sites (K=Karwar; C=Colva).

Phylum: Arthropoda			
Suborder: Cladocera		**Sub class: Copepoda**	
Evadne tergestina	K, C		
Penilia avirostris	K, C	*Euterpina acutifrons*	K, C
Sub class: Copepoda		*Metis* sp.	K
Canthocalanus pauper	K	*Oithona plumifera*	K, C
Eucalanus monachus	K, C	*Oithona similis*	K, C
Rhincalanus sp.	C	*Oithona rigida*	K, C
Calocalanus pavo	K, C	*Oithona brevicornis*	K, C
Paracalanus parvus	K, C	*Oithona* sp.1	K, C
Acrocalanus longicornis	K, C	*Oithona* sp. unidentified (2)	C
Acrocalanus gibber	K	*Corycaeus* sp.	K, C
Centropages furcatus	K, C	**Order: Caligoida**	C
Pseudodiaptomus aurivilli	C	**Class: Ostracoda**	K, C
Pseudodiaptomus serricaudatus	K, C		
Pseudodiaptomus annandalei	K	**Class: Malacostraca**	
Temora turbinata	K, C	**Order: Mysida**	K, C
Candacia discaudata	C	**Order: Amphipoda**	K, C
Labidocera pectinata	K, C	**Order: Isopoda**	K, C
Acartia spinicauda	C	**Order: Cumacea**	K, C
Acartia erythraea	K, C	**Order: Decapoda**	
Acartia centura	K, C	*Penaeus* sp.	K
Acartia negligens	C	*Lucifer* sp.	K, C
Acartia southwelli	C	**Infraorder: Caridae**	K, C
Acartia chilkaensis	C	**Phylum: Chaetognatha**	
Tortanus sp.	K	*Sagitta* sp.1	K, C
Longipedia weberi	K, C	*Sagitta* sp.2	C
Microsetella norvegica	K, C	**Phylum: Urochordata**	
Macrosetella gracilis	C	**Class: Larvacea**	K, C
Miracia efferata	K, C		
Clymnestra scutellata	K, C		

cods were associated with high turbidity and low salinity. *Pseudodiaptomus serricaudatus* were positively correlated with TDS. *Corycaeus* sp. and *Oncea* sp. were seen in large number when there was relatively high DO and low turbidity.

Discussion

The relatively high turbidity in Karwar coastal waters may be attributed to port activities, trawler waste, and erosion. The high readings of turbidity during monsoon may be due to the annual upwelling, which occurs along the central west coast of India during late August and early September (Madhupratap *et al*. 1990; Sankarnarayanan *et al*. 1978). In addition, land runoff, resuspension of fine sediment like clay, silt, organic matter, phytoplankton, and other microscopic organisms also increase the turbidity of the water (Kishore *et al*. 2005). Along the west coast of India, the intensity of upwelling is stronger in the south gradually decreasing moving northward (Madhupratap 1990). Karwar is situated south of Colva and experiences stronger upwelling than Colva. Electrical conductivity was lower in Karwar than in Colva. This may be attributed to the river Kali, which flows into the sea near the Karwar study site. The results of this study suggested that Karwar waters were mainly affected by conditions such as upwelling and dilution of sea water by freshwater from Kali River. While seasonal effects were the main cause of variation in the coastal waters of Colva.

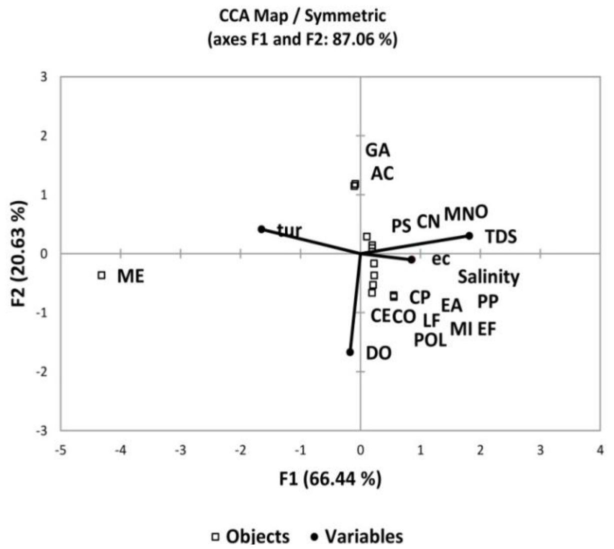

Fig. 5a. Canonical correspondence analysis (CCA) ordination plot for Karwar (Species codes are ME, *Penaeus* sp.; CP, *Calocalanus pavo;* PP, *Paracalanus parvus;* PS, *Pseudodiaptomus serricaudatus*;O, *Oithona* sp.; MN, *Microsetella norvegica*; EA, *Euterpina acutifrons*; MI EF, *Miracia efferata*; POL, Polychaete; CN, copepod nauplii; LF, other larval fish; CE, *Centropages furcatus*; CO,*Corycaeus* sp.; AC, *Acartia* sp.; GA, Gammarid amphipods and the environmental variables tur: turbidity; TDS: total dissolved solids; DO: Dissolved oxygen; ec: electrical conductivity.

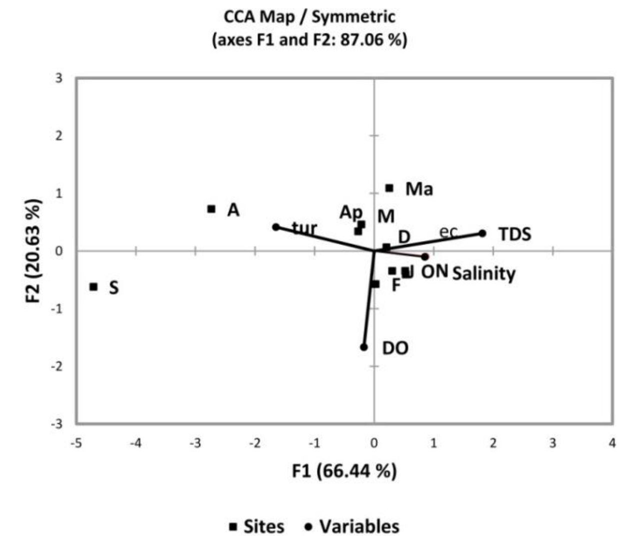

Fig 5b. Canonical correspondence analysis (CCA) ordination plot for Karwar (Months are abbreviated with the first one or two letters of the month, e.g., J, January; M, March; Ap, April; Ma, May) and the environmental variables tur: turbidity; TDS: total dissolved solids; DO: Dissolved oxygen; ec: electrical conductivity.

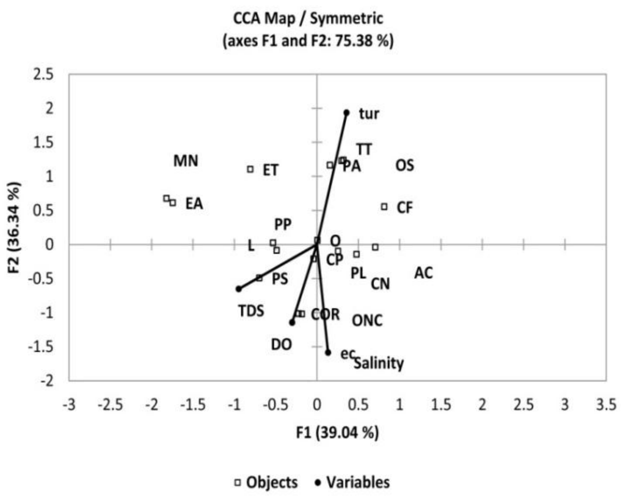

Fig. 6a. Canonical correspondence analysis (CCA) ordination plot for Colva (Species codes are ET, *Evadne tergestina*; PA, *Penilia avirostris*; CP, *Calocalanus pavo*; PP, *Paracalanus parvus*; PS, *Pseudodiaptomus serricaudatus*; O, *Oithona* sp.; MN, *Microsetella norvegica*; EA, *Euterpina acutifrons*; PL, Polychaete; CN, copepod nauplii; CF, *Centropages furcatus*; CO,*Corycaeus* sp.; AC, *Acartia* sp.; ONC, *Oncea* sp.; L, Larvaceae; OS, Ostracods; TT, *Temora turbinata* and the environmental variables tur: turbidity; TDS: total dissolved solids; DO: Dissolved oxygen; ec: electrical conductivity.

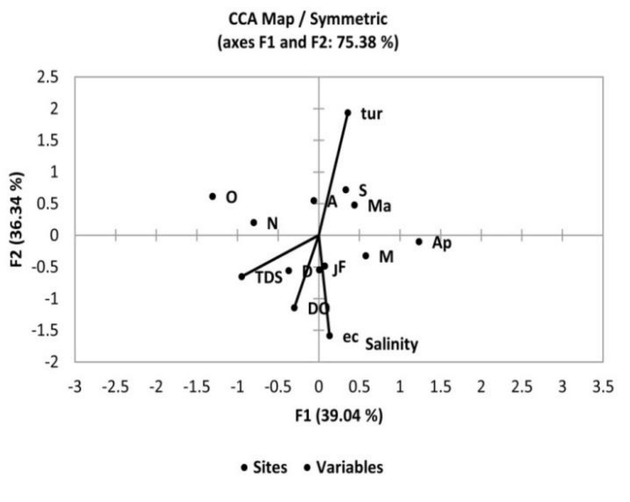

Fig. 6b. Canonical correspondence analysis (CCA) ordination plot for Colva (Refer to Fig. 5b for month and environmental variables abbreviations).

Spatial and temporal variations in zooplankton communities

Two distinct zooplankton assemblages were identified along the central west coast of India. One was in the coastal waters of Karwar and the other in the coastal waters of Colva with comparatively higher salinity. In general, zooplankton composition at Karwar and Colva during the period of investigation was similar to that reported by Naomi (1986) and Goswami & Padmavati (1996), respectively. In monsoon, decapods were the most abundant group in Karwar, the main taxa being commercially important *Penaeus* sp. For the rest of the year, when the turbidity started decreasing and salinity increasing, copepods were the most abundant group. The predominant taxa were *Microsetella norvegica, Canthocalanus pauper,* and *Pseudodiaptomus serricaudatus.* Cladocerans *Evadne tergestina* and *Penilia avirostris* were observed only during the month of October. In contrast, Colva was dominated by a number of species which varied during various seasons. As in many coastal waters (Rai & Reddy 2006; Resmi *et al.* 2011), copepods were the most abundant group in Colva throughout the year. The main taxa included *Calocalanus pavo*, *Eucalanus* sp., *Centropages furcatus*, *Paracalanus pavo,* and *Oithona plumifera*. The appearance of *Corycaeus* sp., a carnivore (Timonin 1971), in Colva resulted in a zooplankton density peak in December. They showed a strong positive correlation with copepod nauplii, suggesting that the copepod nauplii may serve as food source for *Corycaeus* sp.

A major peak in zooplankton density was observed during September (4,990 ± 2,415 ind m^{-3}) in Karwar waters, which was mainly made up of *Penaeus* sp. larvae. A similar peak was reported earlier by Naomi (1986). This peak may be associated with the upwelling in the coastal waters of Karwar. Further, off the coast of Karwar decapods larvae are common and their breeding takes place from October to April (Ramamurthy 1965). Nair & Paulinose (1980) reported a maximum decapod population during the month of October with a steady population during December and January. Achuthankutty *et al.* (1998) recorded the presence of decapods in high numbers at a depth of 30 m in coastal waters of Goa, while the present study recorded less decapods in the surface waters. In marine inshore areas, the decapod fishery is seasonal (from June to September). Upwelled coastal waters are always rich in nutrients and hence provide breeding grounds to many commercially important fishes (C.M.F.R.I. 1987). George (1974) and Menon (1951) have reported that decapods usually feed on organic matter, mud, sand, detritus, and small crustaceans. The occurrence of commercially important *Penaeus* sp. in high densities in Karwar indicates a better potential for a fishery in Karwar in comparison with Colva. There are fishing activities existing in Karwar. Proper harvesting of the *Penaeus* sp. seeds and its export can help the local fisherman improve their economy.

Cladoceran *Evadne tergestina* and *Penilia avirostris* appeared seasonally at both the study sites. Their seasonality is in agreement with the previous reports of Goswami & Padmavati (1996). Atienza *et al.* (2008) reported that the appearance of cladocerans is dominated by two factors: food availability and predators. This may also be applicable in the present study. Cladocerans are filter feeders feeding on nanoplanktons, dinoflagellates, and diatoms (Atienza *et al.* 2006). In the present study, cladocerans and their prey (nanoplanktons, dinoflagellates, and diatoms) occurred abundantly in monsoon. Cladocerans were positively correlated with *Paracalanus parvus* and polychaete sp. which also exhibit similar feeding habits (Ricardo & Humberto 2004). The predators of cladocerans include ctenophores, chaetognaths, and fish larvae (Barz & Hirche 2005) which start appearing in early winter. This might be the reason why cladocerans start decreasing with the onset of winter and almost become negligible in number.

Zooplankton and environmental variables

Turbidity and salinity appeared to be major factors responsible for structuring the zooplankton composition in nearshore coastal waters of Colva and Karwar. A study on zooplankton in the inshore waters of Karwar by Naomi (1986) showed salinity and temperature are important factors controlling zooplankton populations in general and *Paneus* sp. in particular. However, Goswami & Padmavati (1996) did not observe any significant relationship between zooplankton and salinity and temperature in the coastal waters of Goa. In the present study, an inverse relationship was observed between salinity and turbidity in Karwar waters. Such a relationship has been reported earlier by Cyprus & Blaber (1992), while working in a tropical northern Australian estuary. Their study showed that fish densities within the estuary were related to salinity and turbidity but not temperature. The highly turbid and less saline waters of Karwar in monsoon seemed to be favourable to the *Paneus* sp. which is in line with the observations of David *et al.* 2005, who reported high turbidity and mysid biomass in the Gironde estuary in France.

Only the *Penaeus* sp. was able to tolerate the high turbidity and low electrical conductivity and salinity in Karwar in monsoon. A considerable amount of work has been done to show the effect of salinity and temperature on *Penaeus* sp. populations (Jackson & Burford 2003; Ye *et al.* 2009). The study by Jackson showed that salinity in excess of 28 psu did not affect growth and survival of *Penaeus semisulcatus*. At 28 psu, they observed significant decrease in growth rate and survival. However, in the current study salinity was much lower (20 psu in Karwar). On the other hand, Ye *et al.* (2009) subjected *Penaeus monodon* to varied salinity levels ranging from 5 to 35 psu. Their study showed that salinity ranging between 20 to 30 psu was optimal for juvenile *Penaeus*. *Penaeus japonicus* experienced increased mortality from exposure to high turbidity (Lin *et al.* 1992), which contradicts the present study. This is likely due to the fact that Lin *et al.* worked in the laboratory under controlled conditions, while the present study was in an open ocean and turbidity along with salinity seems to be playing a major role in *Penaeus* sp. occurrence. The monsoon conditions in Colva were well suited for *Penilia avirostris* and ostracods, where the turbidity was high, but not as high as in Karwar. *Oncea* sp., *Corycaeus* sp., and *Pseudodiaptomus serricaudatus* were associated with lower turbidity and occurred during post - monsoon and winter seasons. However, *Oithona* sp. occurred less in Karwar than Colva suggesting that the turbid environment does not favor it as indicated by Etilé *et al.* (2012). *Oithona* species are used as bioindicators of good water quality in marine environments (Frangou & Papathanassiou 1991). In the present study, occurrence of *Oithona* in high densities in Colva than Karwar suggests that the waters of Colva have comparatively better water quality than the Karwar waters.

Though phosphate and nitrate concentrations were relatively high during monsoon at both the sites, they remained within the standard concentrations given by Central Pollution Control Board (CPCB), India, 1996. Increase in phosphates and nitrates during monsoon may be due to terrestrial run-off, sewage water and other waters entering the sea, or due to upwelling. If the concentration exceeds a threshold, then there are chances of algal blooms and eutrophication, which can affect zooplankton by decreasing light penetration and dissolved oxygen. But, in the present study no eutrophication was observed.

The present study showed that, the zooplankton composition varies seasonally at Colva and Karwar. Coastal waters of Karwar are likely to serve as breeding grounds for *Penaeus* sp. as these waters are more turbid and less saline and these conditions seem favourable to the *Penaeus*.

Conclusions

It can be concluded from the present study that turbidity and salinity considerably affect zooplankton species composition. In spite of increased anthropogenic activities in the coastal waters under study, eutrophication as measured by N and P concentrations has not yet surfaced in these waters. But if proper measures, like treatment of sewage water before releasing the same into the sea and proper garbage disposal, are not under taken, eutrophication and/or reduced oxygen may result. Occurrence of *Penaeus* sp. very close to the shore can prove as a boon to the fishing community. Proper planning and harvesting of *Penaeus* seeds can result in a good prawn fishery and increased opportunities for the fishing community of the area.

Acknowledgements

The authors express their gratitude to University Grants Commission (UGC) for providing financial assistance in the form of a Major Research Project (F. No. 37-158/2009 SR) to carry out this work. They also express their gratitude to the anonymous reviewers and editors of the journal for their constructive criticism for improving the academic value of the manuscript.

References

Achuthankutty, C. T., R. Neelam & G. Padmavati. 1998. Zooplankton variability and copepod assemblage in the coastal and estuarine waters of Goa along the central-west coast of India. *Pelagic Biogeography* (ICoPB II) **142:** 1-11.

APHA. 1985. *Standard Methods for the Examination of Water and Waste Water*. 16th edn. APHA, Washington, USA.

Atienza, D., E. Saiz, A. Skovgaard, I. Trepat & A. Calbet. 2008. Life history and population dynamics of the marine cladoceran *Penilia avirostris* (Branchiopoda: cladocera) in the Catalan Sea (NW Mediterranean). *Journal of Plankton Research* **30:** 345-357.

Atienza, D., E. Saiz & A. Calbet. 2006. Feeding ecology of the marine cladoceran *Penilia avirostris*: Natural diets, daily ration and prey selectivity. *Marine Ecology Progress Series* **315:** 211-220.

Barz, K. & H. Hirche. 2005. Seasonal development of scyphozoan medusa and the predatory impact of *Aurelia aurita* on the zooplankton community in the Bornholm Basin (central Baltic Sea). *Marine Biology* **147:** 465-476.

Bere, T. 2014. Ecological preferences of benthic diatoms in a tropical river system in Sao Carlos - SP, Brazil. *Tropical Ecology* **55**: 47-61.

Bonsdorff, E., E. M. Blomqvist, J. Mattila & A. Norkko. 1997. Coastal eutrophication: causes, consequences and perspectives in the Archipelago areas of the northern Baltic Sea. *Estuarine, Coastal and Shelf Science* **44** (Suppl. A): 63-72.

Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* **210**:223-253.

C. M. F. R. I. 1987. *An Appraisal of the Marine Fisheries of Karnataka and Goa*. Central Marine Fisheries Research Institute. Special publication no. **36**: 104.

Conway, D. V. P., R. G. White, J. H. D. Ciles, C. P. Gallienne & D. B. Robins. 2003. *Guide to the Coastal and Surface Zooplankton of the South Western Indian Ocean*. Occasional Publication Marine Biological Association of the United Kingdom No. 15, Plymouth.

CPCB. 1996. *Coastal Pollution, Central Pollution Control Board*. Ministry of Environment and Forests, Govt. of India, New Delhi.

Cyprus, D. P. & S. J. M. Blaber. 1992. Turbidity and salinity in a tropical northern Australian estuary and their influence on fish distribution. *Estuarine Coastal and Shelf Science* **35:** 545-563.

David, V., B. Sautour, P. Chardy & M. Leconte. 2005. Long-term changes of the zooplankton variability in a turbid environment: The Gironde estuary (France). *Estuarine Coastal and Shelf Science* **64**: 171-184.

D'Costa, S. & I. K. Pai. 2010. Seasonal variation of zooplankton density along southwest coast of India. *Columban Journal of Life Sciences* **11:** 51-53.

EPA. 1998. *Coastal Water Factsheets- Nearshore Waters and Your Coastal Watershed*. U. S. Environmental Protection Agency Washington, DC. EPA 842-F-98-007.

Etilé, R., M. N. Aka, A. M. Kouassi, M. Pagano & V. N'douba. 2012. Spatio temporal variations in the abundance, biomass, fecundity and production of *Oithona brevicornis* (Copepoda: Cyclopoida) in a west African tropical coastal lagoon (Grand-Lahou, Cote d'Ivoire caught from the backwaters. *Indian Journal of Fisheries* **21:** 495-500.

Frangou, S. & E. Papathanassiou. 1991. Differentiation of zooplankton populations in a polluted area. *Marine Ecology Progress Series* **76**: 41-51.

Gajbhiye, S. N., P. Mehta, S. Mustafa & V. R. Nair. 1994. Fishery potential along the Indian coastal waters between Porbandar and Ratnagiri. *Journal of the Indian Fisheries Association* **24**: 63-72.

George, M. J. 1974. The food of the shrimp *Metapenaeus monoceros* (Fabricus) caught from the backwaters. *Indian Journal of Fisheries* **21**.

Goswami, S. C. 2004. Zooplankton: food for fishes. pp. 75-82. *In*: A. G. Untawale (ed.) *"Know Our Shores: Goa."* Publ. WWF, India.

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

Hedge, V. S., G. Shalini, S. Nayak & A. S. Rajawat. 2008. Nearshore coastal processes between Karwar and Bhatal, central west coast of India: Implications for pollution dispersion. pp. 101-109. *In*: *Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters*. Springer Berlin Heidelberg.

Hernandez, M., I. Robinson, A. Aguilar, L. M. Gonzalez, L. F. Lopez-Jurado, M. I. Reyero, E. Cacho, J. Franco, V. Lopez-Rodas & E. Costas. 1998. Did algal toxins cause monk seal mortality? *Nature* **393**: 28-29.

Islam, S. Md. & M. Tanaka. 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. *Marine Pollution Bulletin* **48**: 624-649.

Iyyapparajanarasimapallavan, G., P. S. Kumar, C. P. Kumar, K. C. A. Jalal, B. Y. Kamaruzzaman & B. A. John. 2013. Distribution and abundance of gelatinous zooplankton along Tamil Nadu coastal waters. *Journal of Biological Sciences* **13**: 18-25.

Jackson, J. C. & M. A. Burford. 2003. The effect of temperature and salinity on growth and survival of larval shrimp *Penaeus semisulcatus* (Decapoda: Penaeoidea). *Journal of Crustacean Biology* **23:** 819-826.

Kasturirangan, L. R. 1963. *A Key for the Identification of the More Common Planktonic Copepod of Indian Coastal Waters*. N. K. Panikkar (ed.) CSIR, New Delhi.

Kishore, K., B. D. Joshi & K. Deepali. 2005. Physico-chemical characteristics of pond water at Kanpur village in Bareilly district (UP). *Himalayan Journal of Environmental Zoology* **19:** 89-92.

KSCZMA. 2008. *Karnataka State Coastal Zone Management Authority*. State of the Environment Report.

Kumar, B. M., R. J. Katti, K. S. V. Moorthy & R. K.

D'Souza. 2004. Macrobenthos in relation to sediment characteristics of nearshore waters of Chitrapur, West coast of India receiving industrial effluents. *Asian Fisheries Science* **17**: 21-28.

Lin, H. P., G. Charmantier, P. Thuet & J. P. Trilles. 1992. Effects of turbidity on survival, osmo-regulation and gill Na^{+}-K^{+} ATPase in juvenile shrimp *Penaeus japonicus*. *Marine Ecology Progress Series* **90**: 31-37.

Madhupratap, M., S. R. S. Nair, P. Haridas & G. Padmavati. 1990. Response of zooplankton to physical changes in the environment: Coastal upwelling along the central west coast of India. *Journal of Coastal Research* **6**: 413-426.

Margalef, R. 1968. *Perspective in Ecological Theory*. Univ. Chicago Press, Chicago, III.

Menon, M. K. 1951. The life history and bionomics of an Indian Penaeid prawn of Cochin area. *Journal of Marine Biological Association of India* **15:** 189-194.

Nair, R. V. & T. V. Paulinose. 1980. Decapod larvae from the nearshore waters of Karwar. *Mahasagar - Bulletin of the National Institute of Oceanography* **13:** 277-280.

Naomi, T. S. 1986. On the zooplankton of the inshore waters of Karwar during 1980-81. *Indian Journal of Fisheries* **33:** 336-346.

NIO. 1972. *Annual Report (1971-72).* National Institute of Oceanography, Goa, India.

Noble, A. 1980. A study on the near shore water of the Karwar bay in the north Kanara coast. *Journal of Marine Biological Association of India* **22:** 70-76.

Noble, A. 1972. Surface temperature and its relation to the duration of mackerel fishery at Karwar. *Indian Journal of Fisheries* **19:** 167-170.

Perry, R. 2003. *A Guide to the Marine Plankton of Southern California*. 3rd edn., UCLA Ocean Globe & Malibu High School.

Pielou, E. 1975. *Ecological Diversity*. Dalhouse University Halifax, Nova Scotia.

Rai, V. & H. Reddy. 2006. Zooplankton and selected hydrographic parameters in the Arabian Sea of Thannirbhavi, Southwest coast of India. *Journal of Indian Hydrobiology* **9:** 83-92.

Ramamurthy, S. 1965. Studies on the plankton of the north Kanara coast in relation to the pelagic fishery. *Journal of Marine Biological Association of India* **7:** 127-149.

Resmi, S., R. V. Reddy, V. K. S. Moorthy & N. Chethan. 2011. Zooplankton dynamics in the coastal waters of Adubidri, Karnataka. *Indian Journal of Geo Marine Sciences* **40:** 134-141.

Ricardo, G. & E. G. Humberto. 2004. Mandible characteristics and allometric relation in copepods: a reliable method to estimate prey size and composition from mandible occurrence in predator guts. *Revista Chilena de Historia Natura* **77:** 607-616.

Robin, R. S., K. V. Vardhan, P. R. Muduli, M. Srinivasam & T. Balasubramanian. 2012. Preponderance of enteric pathogens along the coastal waters of southern Kerala, Southwest coast of India. *Marine Science* **2**: 6-11.

Sankaranarayanan, V. N., D. P. Rao & M. K. Antony. 1978. Studies on some hydrographical characteristics of the estuarine and inshore waters of Goa during the southwest monsoon 1972. *Mahasagar* **11:** 125-136.

SAPWA. 1999. *Standard Analytical Procedures for Water Analysis*. Hydrology Project. Government of India & Government of The Netherlands, CSMRS Building, New Delhi, India.

Sharma, B. K. 2009. Diversity of rotifers (Rotifera, Eurotatoria) of Lotak lake, Manipur, North eastern India. *Tropical Ecology* **50**: 277-285.

Sharma, B. K. 2011. Zooplankton communities of Deepor Beel (a Ramsar site), Assam (N. E. India): ecology, richness and abundance. *Tropical Ecology* **52**: 293-302.

Timonin, A. G. 1971. The structure of plankton communities of the Indian Ocean. *Marine Biology (Berlin)* **9:** 281-289.

Trivedy, R. K. & P. K. Goel. 1987. *Practical Methods in Ecology and Environmental Science*. Environmental Publ., Karad. India.

Ye, L., S. Jiang, X. Zhu, Q. Yang, W. Wen & K. Wu. 2009. Effect of salinity on growth and energy budget of juvenile *Penaeus monodon*. *Aquaculture* **290**: 140-144.

(Received on 30.10.2012 and accepted after revisions, on 05.12.2013)