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Zooplankton distribution in coastal water of the North-Western Bay of Bengal, off Rushikulya estuary, east coast of India

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Abstract

In total, 186 species of holoplankton and 23 different types of meroplankton were encountered during this study. Zooplankton community was dominated by copepods represented by 112 species, belonging to 4 orders and 26 families. Calanoida emerged as the most dominant order among the copepods being comprised of 68 species. It was followed by poicilostomatoids with 26 species, cyclopoids with 10 species and harpacticoida with 8 species. *Paracalanus aculeatus* emerged as the most dominant species during pre-monsoon season while, *Acrocalanus longicornis* was dominant in monsoon and *A. gibber* in the post-monsoon season. Other dominant copepods were *Oithon*a sp., *Miracia efferata*, *Acartia southwelli*, *Centropages tenuiremis*, *Paracalanus parvus*, *Acrocalanus gracilis* and *Acartia erythraea*. Average zooplankton density ranged from 2387 org./10m^3 to 11659 org./10m^3. Zooplankton volume ranged from 0.65 ml/10m^3 in monsoon to 1.51 ml/10m^3 in post-monsoon season. Despite high species abundance during premonsoon period, species diversity was maximum in monsoon. Species richness and dominance indices remained higher during post-monsoon whereas Pielou's evenness (J') was more in monsoon. Non-metric multidimensional scaling (MDS) ordinations based on Bray-Curtis similarities indicated that species composition was unequal during different months as there was no similarity above 40% level.

[**Keywords:** Zooplankton, Copepod, Coastal water, Hydrography, Bay of Bengal]

Introduction

Zooplankton constitutes a broad category and wide range of organisms in marine environment. Roman *et al*[1] have opined that zooplankton are very important to marine pelagic ecosystems, that support higher trophic levels and as the essential determinant of the potential fishery yield. Several microzooplankton species also constitute major food stuff of the larvae of crustaceans, molluscs and fishes while some species of zooplankton are used as water quality indicators[2] and movement of water current[3].

Therefore knowledge on species composition, abundance and distribution of zooplankton was always considered as great significance in marine ecological and fishery management exercises[4]. In recognition of the ecological and economic significance of marine zooplankton, emphasis has been laid to acquire more and more knowledge on species composition, seasonal abundance and reproductive biology of marine and estuarine plankton worldwide leading to accumulation of a plethora of literature. Information relating to zooplankton of coastal waters and estuaries in India has started in early 1900s[5] and it gained momentum from 1950s and 1960s especially after the IIOE. However, majority of studies were confined to areas like Cochin Back waters[6], Mandovi and Zuari estuaries and their neighboring sea[7], Vellar estuary and its adjoining coastal water[8] and Hooghly estuary[9]. Zooplankton studies along Odisha coast in general remained meager and were limited to the Chilika lake[10-12], Rushikulya estuary[13], Bahuda estuary[14], Burhabalanga estuary[15], Mahanadi estuary[16]. The only study on zooplankton distribution in coastal waters along the Odisha coast was that of Sahu *et al*[17]**.** Present paper describes the seasonal variations in zooplankton species composition, population density and relative abundance of major groups in relation to variations in the physico-chemical parameters of north-western Bay of Bengal, off the Rushikulya estuary.

Materials and Methods

The present study was carried out in the Bay of Bengal, off Rushikulya estuary, south Odisha coast. Samples were collected from five stations (Fig.1) at monthly interval from March 2010 to

February 2011. This study area is influenced by fresh water flow via Rushikulya river which receives high quantity of dissolved chemical inputs from many sources including the effluent discharges of a Chloro-alkali plant. The physiographic features, climate, tidal rhythms of the region etc have been discussed earlier[13,18].

Surface water samples were collected using a clean plastic bucket for measurement of hydrographic parameters, nutrients and chlorophyll *a*. Water temperature (WT) and pH were recorded using mercury filled centigrade thermometer and EUTECH field pH reader (accuracy ±0.01) respectively. Water samples for

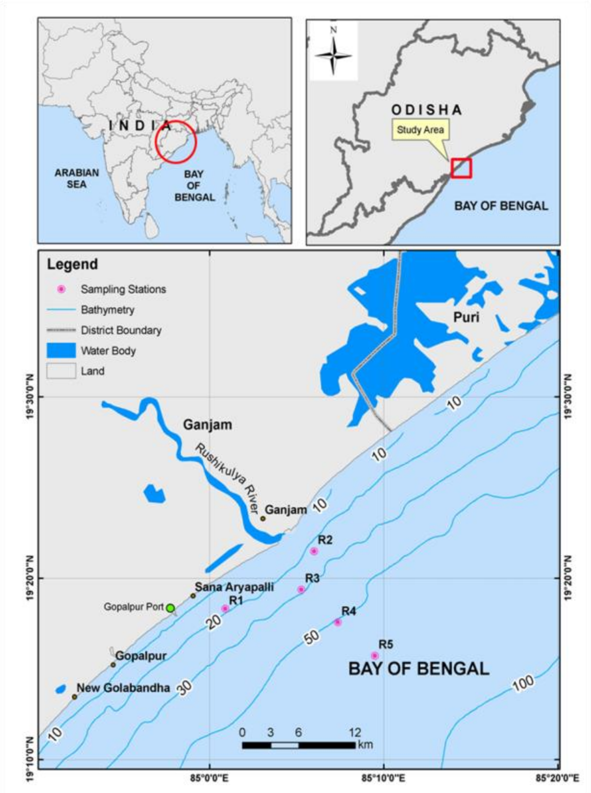

Fig.1. Map showing the sampling locations off Rushikulya estuary

analysis of salinity, nutrients and chlorophyll *a* were collected in clean polyethylene bottles and transported to the laboratory kept in an ice box. Samples for dissolved oxygen (DO) analysis were fixed onboard with Winkler's A and B solutions and were transported to laboratory for further analysis. DO was measured adopting Winkler's method, while salinity was estimated following Knudsen's method[19]. Water samples for nutrient analysis were filtered against glass fiber filter (GF/C) using Millipore Filtering System and were analysed for nitrite (NO_2–N), nitrate (NO_3–N), ammonia (NH_4–N), inorganic phosphate (PO_4–P) and silicate (SiO_4–Si) following the procedures described by Grasshoff *et al*[19]. Chlorophyll *a* was estimated adopting the spectrophotometric method given by Parsons *et al*[20].

Zooplankton samples were collected at each station by horizontal haul using a zooplankton net (mesh size of 120 µm). A digital flow meter (Hydro Bios) was used to determine the volume of water filtered. Samples collected from the receiver were transferred to pre-cleaned polythene bottles and preserved with 5% formaldehyde. In the laboratory, the zooplankton samples were first used for determination of plankton volume through volume displacement method. The residual plankton on the filter paper was re-suspended in 5% formaldehyde and sub-sampling was made using Folsom plankton divider. Subsample was used for quantitative and qualitative analysis. Larger organisms like copepods of families Pontellidae, Eucalanidae, Euchaetidae, Chaetognaths, Dollioloids & Salps were sorted out and counted. Remaining mixture was made to exactly 100 ml and 1 ml of aliquot was transferred on to a Sedgwick–Rafter cell and observed under an inverted microscope (Cippon; Model No.21033) for identification and counting. Total number of macro and micro-zooplankton was taken as the population density. The numerical abundance was presented as org./$10m^3$. Relative abundance was computed from the total density and the density of each group. Identification of zooplankton was done following standard literature[21-23].

Data were grouped into three seasons: premonsoon (PRM), monsoon (MON) and post-monsoon (POM). Analysis of Variance (ANOVA) test was performed to know the inter season comparison of different parameters. Correlation analysis was made to find out the possible relationships between different parameters and zooplankton density. Species diversity indices i.e. Marglef's Species Richness (d), Pielou's Evenness (J'), Shannon Wiener Diversity Index (H' (loge)) and Simpson's Dominance Index (λ) were determined using PRIMER (Plymouth Routines in Multivariate Ecological Research) software Version 5. Zooplankton species composition and abundance from March 2010 - February 2011 was analysed using nonparametric multivariate statistical methods in PRIMER Version 5[24,25] to decipher the similarity in species composition.

Results and Discussion

Seasonally pooled mean and standard deviation values of the hydrographic parameters and nutrients are given in Table 1. Each of the hydrographic parameter such as water temperature (WT), salinity, pH and DO showed well marked seasonal and spatial variations. Monthly collected data showed that water temperature varied from 21.8°C (station R-1, Jan) to 31.4°C (station R-4, May). Seasonally pooled mean temperature values however ranged from 26.0°C to 28.9°C. Higher temperature was recorded in PRM season while lower temperature was observed during POM months. Temperature over the Bay of Bengal mainly depends on climatic variations especially the atmospheric conditions and rain fall[26]. Temperature variations during the present study could also be ascribed to seasonal changes in atmospheric conditions and rainfall. Monthly recorded salinity values ranged from 25.3 PSU (station R-1, August) to 35.8 PSU (station R-5, January). Seasonally pooled average salinity ranged from 30.58 PSU during MON season to 31.79 PSU during PRM period.

Table 1. Variations of physicochemical and biological parameters

St.	WT (°C)	pH	DO (mg/L)	Salinity (PSU)	NO_2 (μmol/L)	NO_3 (μmol/L)	NH_4 (μmol/L)	PO_4 (μmol/L)	SiO_4 (μmol/L)	Chl-*a* (mg/ m^3)	ZooBio (ml/10m^3)	ZooPop (Org./10m^3)
						PREMONSOON						
R-1	27.7	7.66	8.02	28.89	0.36	2.06	2.4	2.14	6.13	5.67	0.98	23054
R-2	28.3	7.97	7.78	29.7	0.32	1.66	2.47	1.25	4.72	2.51	1.39	11556
R-3	29.0	8.24	7.64	32.27	0.4	1.4	2.15	1.16	5.32	2.59	0.80	11234
R-4	29.6	8.29	7.86	33.26	0.27	0.93	1.37	0.91	5.02	1.59	1.37	8184
R-5	30.0	8.02	7.67	34.83	0.4	1.08	1.47	1.59	4.58	1.7	0.14	4270
Mean	28.9	8.04	7.79	31.79	0.35	1.43	1.97	1.41	5.15	2.81	0.93	11659
SED	1.0	0.25	0.15	2.47	0.06	0.45	0.52	0.48	0.62	1.66	0.51	7012
						MONSOON						
R-1	26.3	7.51	8.02	26.94	0.46	1.26	1.72	2.41	7	2.16	1.38	5958
R-2	26.7	7.77	7.71	28.91	0.49	1.17	2.07	1.46	5.45	1.81	0.86	2416
R-3	27.1	8.07	7.64	32.31	0.42	0.93	1.35	1.31	4.82	1.99	0.54	1077
R-4	27.9	8.27	7.43	31.43	0.37	0.98	1.81	0.77	5.83	1.48	0.35	1129
R-5	27.9	8.3	7.31	33.33	0.3	0.97	1.67	0.85	3.11	1.29	0.16	1354
Mean	27.2	7.98	7.62	30.58	0.41	1.06	1.72	1.36	5.24	1.75	0.65	2387
SED	0.7	0.34	0.27	2.61	0.08	0.14	0.26	0.66	1.43	0.36	0.48	2069
						POST MONSOON						
R-1	24.7	8.11	8.46	27.66	0.38	1.82	2.19	2.98	9.23	1.75	2.53	10226
R-2	26.0	8.14	7.32	30.08	0.29	2.05	2.24	1.29	7.75	1.73	1.55	4500
R-3	26.2	8.15	7.43	30.95	0.42	1.89	5.06	1.01	6.01	1.85	1.59	8848
R-4	26.4	8.18	7.58	32.54	0.42	1.28	1.8	1.04	6.78	1.84	0.33	2619
R-5	26.5	8.19	7.29	32.62	0.28	1.24	2.53	0.95	7.07	1.85	1.52	2433
Mean	26.0	8.15	7.62	30.77	0.36	1.66	2.76	1.45	7.37	1.8	1.51	5725
SED	0.7	0.03	0.49	2.05	0.07	0.37	1.31	0.86	1.21	0.06	0.78	3606

Trend of salinity variation was PRM >POM >MON. Lower salinity values during MON season could be attributed to the combined influence of rainfall and freshwater influx from landward sources. Similar type of seasonal variation in salinity was observed in coastal waters of Kalpakkam, East coast of India by Satpathy *et al*[27]. Temperature showed positive correlation ($p<0.05$) with salinity indicating their strong affinity. Results of one way ANOVA (Table 2) also explained well defined seasonal variation in water temperature ($p<0.01$). Monthly measured pH values varied between 7.14 (station R-1, July) and 8.58 (station R-4, September), whereas the seasonally pooled mean value lied between 7.98 (MON) and 8.15 (POM). Average pH in PRM season was 8.04. The higher values of POM and PRM seasons could be due to high salinity and high photosynthetic activity as observed by Subramanian and Mahadevan[28] along Chennai coast. Monthly observed DO values ranged from 6.45 (station R-4, Dec.) – 8.75 (station R-4, Nov). Season-wise average DO values showed that maximum value of 7.79 mg /L was encountered in the PRM period. More fluctuation in DO was however observed during POM season (SD: 0.49 mg /L). High surface values of DO during PRM season could be ascribed to the addition of DO by phytoplankton photosynthesis as reported in Kalpakkam coastal waters[29].

Table 2. One way ANOVA results of hydrographic and biological parameters 2010-11

Parameters	p Value
WT	**0.000**
pH	0.273
DO	0.461
Salinity	0.304
NO_2	0.484
NO_3	**0.002**
NH_4	0.193
PO_4	0.976
SiO_4	**0.022**
Chl-*a*	**0.042**
Zoo Density	**0.005**

*Significant level p<0.05 in bold

Nitrite (NO_2-N), the most unstable form of nitrogen in sea water, exhibited wide range of variation. The monthly values varied from 0.06 µmol/L (station R-5, Feb) to 0.85 µmol/L (station R-4, Nov). Season-wise pooled mean NO_2-N was maximum during MON (0.41 µmol/L), while it remained minimum during the PRM (0.35 µmol/L) season. Monthly values of NO_3-N ranged from 0.58 (station R-4, Feb) to 3.13 µmol/L (station R-3, Feb). The negative correlation ($r = -0.552$, $p < 0.05$) between salinity and nitrate denotes that freshwater forms major contributor of nitrate in coastal waters. Monthly NH_4 –N varied from 0.8 (station R-5, Feb) to 15.4 µmol/L (station R-3, Dec) while seasonal average values ranged between 1.72 (MON) to 2.76 (POM) µmol/L. Monthly values of PO_4–P varied between 0.17 - 8.86 µmol/L with maximum concentration observed at station R-1 in November 2010. Average seasonal values however ranged from 1.36 (MON) to 1.45 (POM) µmol/L. Like nitrate, phosphate concentrations also exhibited negative correlation with salinity ($r = -0.712$, $p<0.01$), indicating thereby this nutrient too is controlled by fresh water influx. The SiO_4-Si concentration ranged between 0.64 (station R-5, June) to 18.42 (station R-2, Feb) µmol/L. SiO_4-Si concentration was maximum (7.37±1.21 µmol/L) in POM as compared to PRM (5.15±0.62 µmol/L) and MON (5.24±1.43 µmol/L) seasons. The strong negative correlation ($r = -0.583$, $p<0.05$) of silicate and salinity suggests its input via freshwater. Results of ANOVA test (Table 2) showed more significant seasonal variation in NO_3-N ($p<0.01$) and SiO_4-Si ($p<0.05$) contents in the study area. The higher value of nutrients in MON season and their negative correlation with salinity establishes their entry through freshwater as was reported along the Coromandel Coast[30] and coastal waters of Gopalpur[31].

Phytoplankton is the ultimate source of food for zooplankton. Chlorophyll *a* is the best index of phytoplankton standing stock as such it has direct bearing on the growth of zooplankton. Seasonally pooled mean chlorophyll *a* was at its maximum in PRM (2.81 mg/m^3) that fell to minimum in MON (1.75 mg/m^3). Higher chlorophyll *a* contents in PRM season is a common feature in surface waters of the Bay of Bengal. When all the seasons were taken in to consideration for ANOVA, significant seasonal variation was observed in chlorophyll *a* ($p<0.05$) distribution.

Monthly values of plankton volume ranged from 0.02 (station R-4, May and station R-3 June) to 6.40 ml/10m^3 (station R-1, Feb). Higher volume of plankton at station R-1 during Feb might be due to the presence of caridean larvae, brachyuran zoea larvae, chaetognaths and larger sized copepod species. Seasonally pooled mean plankton volume ranged from 0.65 ml/10m^3 in MON to 1.51 ml/10m^3 in POM. In PRM, the pooled mean of plankton volume was 0.93 ml/10m^3. More fluctuation (SD: 0.78 ml/10m^3) in plankton volume was observed during POM season followed by pre-monsoon (SD: 0.51 ml/10 m^3) and monsoon (SD: 0.48 ml/10m^3). Significant positive correlation ($r = 0.275$, $p<0.05$) was noticed between zooplankton volume and density.

The systematic account of zooplankton encountered during the course of study are presented in Table 3 and Table 4. In total, 186 species of holoplankton belonging to 12 groups such as Acantharia, Ciliophora, Foraminifera, Hydrozoa, Ctenophora, Gastropoda, Cladocera, Copepoda, Ostracoda, Malacostraca, Chaetognatha, Chordata and 23 different types of meroplankton were recorded**.** The holoplankton components depending upon their abundance are broadly described under three groups namely copepods, other crustaceans and non crustaceans. Copepods formed the most dominant group throughout the study period.

Copepod not only remained as the most dominant group but also appeared in large numbers at all the stations round the year. They were represented by 112 species, belonging to 26 families and 4 orders. Calanoida emerged as the most dominant group comprising 68 species followed by poicilostomatoids with 26 species, cyclopoids with 10 species and harpacticoid with 8 species. The dominance of calanoida over others could be due to their continuous breeding, quick larval development and adaptation to wide range of environmental conditions as reported earlier[8,32]. Further, among the calanoida, *Paracalanus aculeatus* remained as the most dominant component in PRM season, while *A. longicornis* remained dominant in MON and *A. gibber* in POM season**.** Rakesh *et al*[33] have reported that both *Paracalanus* sp. and *Acrocalanus* sp. were characterizing the coastal locations off North Coastal Andhra Pradesh and the findings of the present study corroborated the same. *Canthocalanus pauper* and *Acrocalanus longicornis* were frequently observed throughout the year justifying their cosmopolitan behavior. Among cyclopoida, *Oithona similis, O. brevicornis, O. spinirostris, Oithona sp.* appeared as common species in all the three seasons. High abundance of *Oithona* sp. could be due to its high reproductive capability as opined by Santhanam and Perumal[8] and Santosh Kumar and Perumal[34]. Although species like *Miracia efferata, Macrosetella gracilis, Macrosetella oculata, Microsetella norvegica, Microsetella rosea,*

Table 3. Check list of zooplankton (Holoplankton) encountered in the coastal waters of south Odisha coast, off Rushikulya estuary during 2010-11

Phylum:Class	S.class	Order	Family	Species
Protozoa: Acantharia		Arthracanthida	Acanthometridae	*Acanthometron* sp. J. Muller (1856)
Ciliophora: Spirotrichea	Choreotrichia	Tintinnida	Tintinnidiidae	*Leprotintinnus nordqvisti* Brandt (1906)
			Codonellidae	*Tintinnopsis beroidea* Stein (1867)
				T. butschlii Daday (1887)
				T. cylindrica Daday (1887)
				T. mortensenii Schmidt (1901)
				T. tocantinensis Kofoid and Campbell (1929)
				T. tubulosa Levander (1900)
				T. uruguayensis Balech(1948)
			Codonellopsidae	*Codonellopsis ostenfeldi* Schmidt (1901)
			Dictyocystidae	*Dictyocysta seshaiyai* Krishnamurthy & Santhanam (1975)
			Metacylididae	*Metacylis jorgenseni* Cleve (1902)
			Rhabdonellidae	*Rhabdonella sp.*Brandt (1906)
			Tintinnidae	*Amphorellopsis* sp. Kofoid and Campbell (1929)
				Eutintinnus tenue Kofoid and Campbell (1929)
			Xystonellidae	*Favella philippinensis* Roxas (1941)
Foraminifera: Polythalamea		Globigerinida	Globigerinidae	*Globigerina bulloides* d'Orbigny (1826)
				G.rubescense Hofker (1956)
				Globigerina sp. d'Orbigny (1826)
		Rotaliida	Rotaliidae	*Asterorotalia trispinosa* Thalmann (1933)
		Miliolida	Miliolidae	*Quinqueloculina* sp. d'Orbigny(1826)
Cnidaria: Hydrozoa	Hydroidomedusae	Anthomedusae	Cladonemidae	*Cladonema* sp. Dujardin (1843)
			Corynidae	*Sarsia* sp. Lesson(1843)
			Hydractiniidae	*Podocoryne* sp. Luetken (1850)
		Leptomedusae	Campanulariidae	*Obelia* sp. Péron & Lesueur (1810)
			Phialellidae	*Phialella quadrata* Forbes (1848)
		Trachymedusae	Geryoniidae	*Liriope tetraphylla* Chamisso and Eysenhardt (1821)
			Rhopalonematidae	*Aglaura hemistoma* Peron and Lesueur (1810)
		Conica	Aequoreidae	*Aequorea vitrina* Gosse (1853)
	Siphonophorae	Physonectae	Agalmatidae	*Agalma elegans* Sars (1846)

		Calycophorae	Diphyidae	*Sulculeolaria* sp. Blainville (1830)
				Diphyes chamissonis Huxley (1859)
				D. dispar Chamisso and Eysenhardt (1821)
				Diphyes sp. Cuvier (1817)
				Lensia sp Totton (1932)
				Eudoxoides mitra Huxley (1859)
				Muggiaea sp. Busch (1851)
			Abylidae	*Abylopsis* sp. Chun (1888)
				Bassia bassensis Quoy and G-aimard (1833) 1834)
Ctenophora: Tentaculata	Typhlocoela	Cydippida	Pleurobrachiidae	*Pleurobrachia pileus* O. F. Müller (1776)
Ctenophora: Nuda		Beroida	Beroidae	*Beroe* sp. Gronov (1760)
Mollusca: Gastropoda	Streptoneura	Mesogastropoda	Atlantidae	*Atlanta* sp. Lesueur (1817)
			Janthinidae	*Janthina* sp. Röding (1798)
	Euthyneura	Thecosomata	Limacinidae	*Limacina bulimoides* d'Orbigny (1834)
				Limacina inflata d'Orbigny (1834)
			Cavoliniidae	*Cresis acicula* Rang (1828)
				Hyalocylix striata Rang (1828)
Arthropoda: Branchiopoda	Phyllopoda	Cladocera	Podonidae	*Evadne tergestina* Claus (1864)
			Sididae	*Penilia avirostris* Dana (1849)
Arthopoda: Maxillipoda	Copepoda	Calanoida	Metridinidae	*Pleuromamma* sp. Giesbrecht in Giesbrecht & Schmeil (1898)
			Acartiidae	*Acartia . centrura* Giesbrecht (1889)
				A. danae Giesbrecht (1889)
				A. erythraea Giesbrecht (1889)
				A. spinicauda Giesbrecht (1889)
				A. negligens Dana (1849)
				A. southwelli Sewell (1914)
				Acartia sp. Dana (1846)
			Candaciidae	*Candacia catula* Giesbrecht (1889)
				Candacia sp. Dana (1846)
				Paracandacia truncata Dana (1849)
				Paracandacia sp. Grice (1963)
			Centropagidae	*Centropages alcocki* Sewell (1912)
				C. furcatus Dana (1849)
				C. calaninus Dana (1849)
				C. dorsispinatus Thompson I.C. & Scott A.(1903)
				C. orsinii Giesbrecht (1889)
				C. tenuiremis Thompson I.C. & Scott A.(1903)
				Centropages sp. Kroyer (1849)
			Pontellidae	*Calanopia minor* A. Scott (1902)
				C. elliptica Dana (1846, 1849)
				Labidocera acuta Dana (1849)
				L. detruncata Dana (1849)
				L. minuta Giesbrecht (1889)
				L. pectinata Thompson I.C. & Scott A. (1903)

		Labidocera sp. Lubbock (1853)
		Pontella fera Dana (1849)
		P. securifer Brady (1883)
		Pontellina platychela Fleminger and Hülsemann (1974)
	Temoridae	*Temora discaudata* Giesbrecht (1889)
		T. turbinata Dana (1849)
		T. stylifera Dana (1849)
	Tortanidae	*Tortanus barbatus* Brady (1883)
		T. forcipatus Giesbrecht (1889)
		T. gracilis Brady (1883)
	Calanidae	*Mesocalanus tenuicornis* Dana (1849)
		Canthocalanus pauper Giesbrecht (1888)
		Nannocalanus minor Claus (1863)
		Undinula vulgaris Dana (1849)
	Paracalanidae	*Acrocalanus gracilis* Giesbrecht (1888)
		A. longicornis Giesbrecht (1888)
		A. gibber Giesbrecht (1888)
		Acrocalanus sp. Giesbrecht (1888)
		Calocalanus pavo Dana (1849)
		Paracalanus aculeatus Giesbrecht (1888)
		P.parvus Claus (1863)
		Paracalanus sp. Boeck (1865)
	Eucalanidae	*Eucalanus attenuatus*Dana (1849)
		E. monachus Giesbrecht (1888)
		Eucalanus sp. Dana (1852)
		Subeucalanus crassus Giesbrecht (1888)
		S. mucronatus Giesbrecht (1888)
		*S. pileatus*Giesbrecht (1888)
		*S. subcrassus*Giesbrecht (1888)
		*S. subtenuis*Giesbrecht (1888)
	Aetideidae	*Undeuchaeta sp.*Giesbrecht (1888)
	Arietellidae	*Metacalanus aurivilli* Cleve (1901)
	Clausocalanidae	*Clausocalanus arcuicornis*Dana (1849)
	Euchaetidae	*Euchaeta concinna* Dana (1849)
		E. marina Prestandrea (1833)
		Euchaeta sp.Philippi (1843)
	Scolecitrichidae	*Scolecithrix danae* Lubbock (1856)
		Scolecithricella minor Brady (1883)
	Pseudodiaptomidae	*Pseudodiaptomus aurivilli* Cleve (1901)
		P. serricaudatus T.Scott 1894)
		P. annandalei(Sewell, 1919)
		Pseudodiaptomus sp.(Herrick, 1884)
	Augaptilidae	*Haloptilus* sp. Giesbrecht in Giesbrecht & Schmeil (1898)
Cyclopoida	Oithonidae	*Oithona nana* Giesbrecht (1892)
		O. oculata Farran (1913)
		O. setigera Dana (1849)

				O. similis Claus (1866)
				O. simplex Farran (1913)
				O. tenuis Rosendorn (1917)
				O. rigida Giesbrecht (1896)
				O. brevicornis Giesbrecht (1891)
				O. spinirostris Claus (1863)
				Oithona sp. Baird (1843)
		Harpacticoida	Miraciidae	*Miracia efferata* Dana (1849)
				Macrosetella gracilis Dana (1848)
				M. oculata Sars G.O. (1916)
			Ectinosomatidae	*Microsetella norvegica* Boeck (1864)
				M. rosea Dana (1848)
			Clytemnestridae	*Clytemnestra scutellata* Dana (1848)
			Euterpinidae	*Euterpina acutifrons* Dana (1848)
			Longipediidae	*Longipedia weberi* Scott A. (1909)
		Poecilostomatatoida	Oncaeidae	*Oncaea conifera* Giesbrecht (1891)
				O. media Giesbrecht (1891)
				O. mediterranea Claus (1863)
				O. venusta Philippi (1843)
				Oncaea sp.Philippi (1843)
			Sapphirinidae	*Copilia quadrata* Dana (1849)
				Sapphirina auronitens Claus (1863)
				S. maculosa Giesbrecht (1892)
				S. ovatolanceolata Dana (1849)
				Sapphirina sp. Thompson J. (1829)
			Corycaeidae	*Corycaeus agilis* Dana (1849)
				C. andrewsi Farran (1911)
				C. catus F. Dahl (1894)
				C. danae Giesbrecht (1891)
				C. erythraeus Cleve (1904)
				C. lautus Dana (1849)
				C. longistylis Dana (1849)
				C. ovalis Claus (1863)
				C. robustus Giesbrecht (1891)
				C. speciosus Dana (1849)
				Corycaeus sp. Dana (1845)
				Farranula carinata Giesbrecht (1891)
				F. concinna Dana (1849)
				F.curta Farran (1911)
				F. gibbula Giesbrecht (1891)
				F. gracilis Dana (1849)
Arthropoda: Ostracoda	Myodocopa	Myodocopida	Cypridinidae	*Macrocypridina castanea* Brady (1897)
		Halocyprida	Halocyprididae	*Conchoecia elegans* Sars (1865)
				Euconchoecia chierchiae G. W. Müller (1890)
Arthropoda: Malacostraca	Eumalacostraca	Mysida	Mysidae	*Mesopodopsis orientalis* W. Tattersall (1908)
		Amphipoda	Leucothoidae	*Leucothoe spinicarpa* Abildgaard (1789)

		Hyperiidae	*Hyperia* sp. Latreille (1823)
		Caprellidae	*Caprella* sp. Lamarck (1801)
			Metacaprella sp. Mayer (1903)
		Talitridae	*Orchestoidea* sp. Nicolet (1849)
	Cumacea	Nannastacidae	*Campylaspis costata* Sars (1865)
	Euphausiacea	Euphausiidae	*Euphausia tenera* Hansen (1905)
			Euphausia sp. Dana (1850)
	Decapoda	Luciferidae	*Lucifer hanseni* Nobili (1905)
		Sergestidae	*Sergestes* sp. H. Milne Edwards (1830)
Chaetognatha: Sagittoidea	Aphragmophora	Sagittidae	*Pseudosagitta maxima* Conant (1896)
			Sagitta bedoti Beraneck (1895)
			S. bipunctata Quoy & Gaimard (1828)
			S. enflata Grassi (1881)
			Sagitta sp. Quoy & Gaimard (1827)
			Adinosagitta bedfordii Doncaster (1903)
Chordata: Appendicularia	Copelata	Oikopleuridae	*Oikopleura dioica* Fol (1872)
			O.parva Lohmann (1896)
		Fritillariidae	*Fritillaria* sp. Fol (1872)
Chordata: Thaliacea	Doliolida	Doliolidae	*Doliolum* sp. Quoy & Gaimard (1834)
	Salpida	Salpidae	*Salpa fusiformis* Cuvier (1804)

Clytemnestra scutellata, Euterpina acutifrons, Longipedia weberi of the harpacticoid were encountered as common species in this locality, only two species *viz. Euterpina acutifrons* and *Longipedia weberi* were more frequent. Three families *viz.* Oncaeidae, Sapphirinidae and Corycaeidae have represented the poiecilostomatoida in which Corycaeidae with species *Corycaeus agilis, Corycaeus andrewsi, C. catus, Corycaeus sp. and Farranula gibbula* were dominant. Many times *Oncaea venusta* has also occurred quite frequently and that could be due to its diverse feeding habit and respiratory adaptation as opined earlier[35]. Seasonal variation in species dominance was observed in this part of Bay of Bengal. During premonsoon and monsoon season, *Paracalanus aculeatus* and *Acrocalanus longicornis* proved to be the most dominant species. Other species *viz. Oithona* sp., *Miracia efferata* and *Acrocalanus gibber* were dominant during premonsoon, while *Acartia southwelli, Acartia erythraea* and Oithona sp. were dominant during monsoon season. Faunal composition of copepod remained significantly different during post-monsoon period than premonsoon and monsoon season. The most dominant species were *Acrocalanus gibber*, *Centropages tenuiremis*, *Paracalanus parvus*, *Acrocalanus gracilis* and *Acartia erythraea*. Dominance of low saline species of genus *Paracalanus, Acartia and Acrocalanus* in most part of the year indicate the estuarine influence in the study area.

The other crustacean fauna of the present study mainly belonged to three classes namely Malacostraca (mysids, cumaceans, euphausiids, amphipods and decapods), Ostracoda (ostracods) and Branchiopoda (cladocerans). In total 2 species of Cladocerans *viz. Evadne tergestina* and *Penilia avirostris* were encountered. They were more abundant (302 org./ $10m^3$) during POM season compared to other seasons. *Evadne tergestina* was commonly seen in plankton collections of POM period. Ostracoda population comprised of myodocopida mainly *Macrocypridina castanea* and halocyprida consisting of *Conchoecia elegans* and *Euconchoecia chierchiae*. The ostracoda population was represented by 3 species *viz*., *Macrocypridina castanea, Conchoecia elegans* and *Euconchoecia chierchiae* as against only one species i.e. *Philomedes* sp earlier[17]. Malacostraca comprised of 11 species belonging to 5 orders. Out of these 11 species, *Lucifer hanseni* occurred all year round and exhibited peak dominance during PRM period. This could be due to the fact that the Bay of Bengal remains more productive in this season and that supports for high Decapoda density.

The Protozoa population was represented by one species *Acanthometron* sp. of class Acantharia that occurred only in May and 15 species belonging to 8 families of class Ciliophora. Ciliophora population comprised of *Leprotintinnus nordqvisti, Tintinnopsis beroidea, Tintinnopsis butschlii, Tintinnopsis cylindrica, Tintinnopsis mortensenii, Tintinnopsis tocantinensis, Tintinnopsis tubulosa, Tintinnopsis uruguayensis, Codonellopsis ostenfeldi, Dictyocysta seshaiya, Metacylis jorgenseni, Rhabdonella* sp., *Amphorellopsis* sp., *Eutintinnus tenue, Favella philippinensis*. They were present during March, June, July, August, October, December 2010 and January 2011. The tintinnid population of this study resembled those in Bahuda estuary[2], Vellar-Coleroon estuary[36] and coastal regions of Sundarban mangrove wetland[37]. Foraminifera were represented by 5 species *viz. Globigerina bulloides, Globigerina rubescens, Globigerina* sp., *Asterorotalia trispinosa* and *Quinqueloculina* sp. and were common during March - May and November - February.

Table 4. Check list of zooplankton (Meroplankton) encountered in the coastal waters of south Odisha coast, off Rushikulya estuary during 2010-11

Meroplankton
Actinula larva of Anthomedusae
Alima larva of Squilla
Brachiopod larvae
Brachyuran zoea larvae
Bryozoan cyphonautes larvae
Caridean larvae
Cypris larvae (Barnacle)
Cirripede nauplii (Barnacle)
Copepod nauplii
Gastopod veliger
Bivalve veliger
Isopod larvae
Larvae of euphausiids
Megalopa larvae of Brachyuran crab
Megalopa larvae of Pagurid crab
Planula larva of obelia
Polychaete larva
Protozoea of Lucifer
Zoea larva of porcelain crab
Echinoderm larvae
Ascidians larvae
Fish egg
Fish larvae

Hydrozoa of phylum Cnidaria were represented by 18 species belonging to two classes namely hydroidomedusae and Siphonophorae. They were present throughout the year except in September. The peak period of Siphonophorae occurrence was observed during February and March. *Diphyes dispar* appeared as the most common siphonophorae in this area.

Ctenophora was represented by two families i.e. Pleurobrachiidae and Beroidae with a single species *viz. Pleurobrachia pileus* and *Beroe* sp. respectively. *P. pileus* was commonly seen during MON and POM and was completely absent during PRM season. *Beroe* sp. on the other hand had occurred only during POM and its population size was poor.

Phylum Mollusca was represented by Gastropoda comprising of 6 species namely *Atlanta* sp., *Janthina* sp., *Limacina bulimoides, Limacina inflata, Cresis acicula* and *Hyalocylix striata*. Among these species *Cresis acicula* was dominant which occurred in greater part of the year. Its presence was more conspicuous in March and December.

The Chaetognatha population was represented by six species *namely Pseudosagitta maxima*, *Sagitta bedoti*, *Sagitta bipunctata*, *Sagitta enflata*, *Sagitta* sp. and *Adinosagitta bedfordii* under a single family Sagittidae. They were more abundant during the PRM and POM months. *Sagitta enflata* was the most dominant species during our study which is comparable to many observations[38].

Planktonic chordates of the region were represented by 3 species of appendicularians *viz. Oikopleura dioica, Oikopleura parva* and *Fritillaria* sp. and one species each of Dollioloids (*Dolliolum* sp.) and salps (*Salpa fushiformis). O. dioica* however remained as the most common species among the appendicularians with high abundance during March compared to other months.

Meroplankton was represented by 23 forms during the study. They were more abundant during the PRM period compared to other season. Among these 23 forms, bivalve veliger, brachyuran zoea larva, caridean larva, cirripede nauplii, copepod nauplii, fish egg & larvae, gastropod veliger, polychaete larva, protozoea of lucifer were frequently observed throughout the year.

Species diversity of plankton community exhibited well marked fluctuations (Table 7). The Shannon Wiener Diversity index (H' (loge)) was higher in February (3.41), while the Margalef's species richness (d) (8.32) & Simpson's dominance (λ) (0.22) in January, and Pielou's evenness (J') in February (0.78). Higher

Simpson's Dominance (λ) (0.22) as well as lower Shannon Wiener Diversity index (2.02) during January might be due to the dominance of species like *Paracalanus parvus, Farranula gibbula, Corycaeus erythraeus*. Seasonally the Shannon diversity and evenness of zooplankton community were generally higher in monsoon while richness and dominance during POM period.

Table 5 and Fig. 2 represents the population density and percentage composition of different groups of zooplankton respectively. The population density of zooplankton exhibited wide range of spatial and seasonal variations. The average density varied between 1077 org./10m^3 (station R-3 in MON) and 23060 org. /10m^3 (station R-1 in PRM). The seasonally pooled

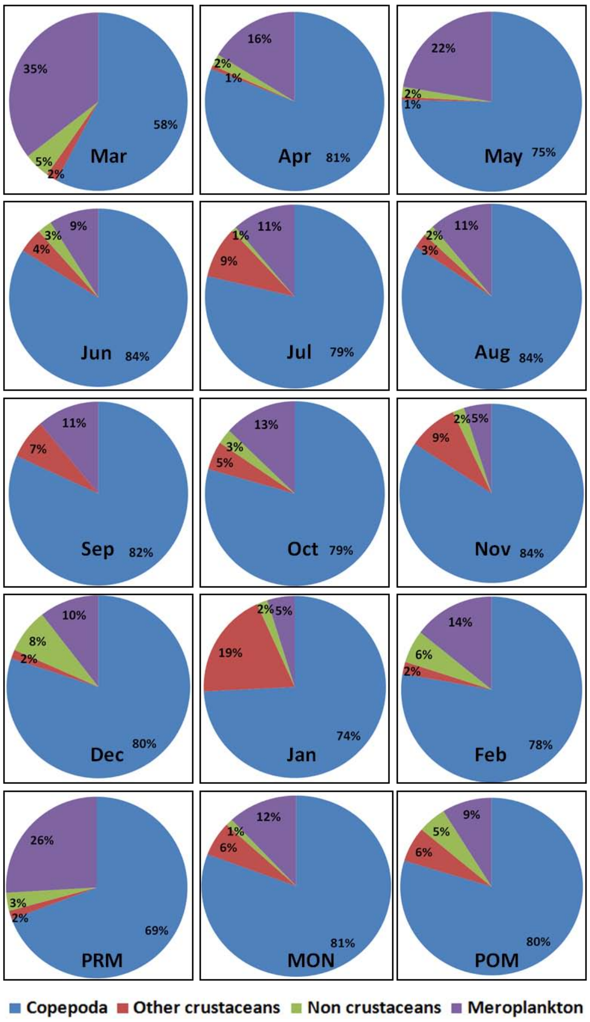

Fig.2.Relative abundance of zooplankton community during 2010-11

Table 5. Monthly variation in population size of different zooplankton groups during 2010-11

Major Groups	Mar	Apr	May	Jun	PRM	Jul	Aug	Sep	Oct	MON	Nov	Dec	Jan	Feb	POM
Acantharia	0	0	37	0	9	0	0	0	0	0	0	0	0	0	0
Ciliophora	29	0	0	6	9	1	2	0	38	10	0	5	0	0	1
Foraminifera	35	6	37	0	19	0	0	0	0	0	3	87	3	12	26
Hydrozoa	236	99	51	21	102	1	6	0	12	5	43	26	7	73	37
Gastropoda	161	11	0	29	50	3	2	0	4	2	6	403	2	77	122
Cladocera	141	0	0	27	42	72	1	107	92	68	411	12	725	58	302
Copepoda	11946	7731	9677	2979	8083	1141	1062	3067	2438	1927	4799	7627	2837	2996	4565
Ostracoda	37	0	0	58	24	16	9	0	21	12	0	2	0	5	2
Malacostraca	232	65	69	74	110	45	23	157	41	67	89	137	0	17	61
Chaetognatha	0	71	40	25	34	6	14	0	21	10	29	220	35	51	84
Chordata	520	17	69	13	155	1	1	0	6	2	33	6	25	8	18
Meroplankton	7342	1554	2872	320	3022	166	144	423	402	284	277	1005	187	557	507

average zooplankton density showed that the rank order distribution of population size in different seasons (Table 1) are PRM (11659 org./10m^3) > POM (5725 org./10m^3) > MON (2387 org./10m^3). The higher PRM population density of zooplankton of the present study coincides with many earlier reports from the coastal waters of Indian seas[34, 39] and other literature cited thereon. Station-wise population density of different groups of zooplankton during PRM period have shown that the rank order distribution of different groups is copepod > larvae > malacostraca >

others in station R-1 and R-2, whereas in station R-3 and R-5 the population density although followed the same sequence, appendicularia has occupied the 3rd place in place of malacostraca followed by others. At station R-4, the rank order distribution stands as copepod > larvae > hydrozoa. Similar to PRM, the rank order distribution of population density of MON season showed that , copepods, larvae and malacostraca occupied the 1st, 2nd and 3rd position in order of their dominance at stations R-1, R-2 and R-5, while at stations R-3 and R-4, branchiopoda was in third position in place of malacostraca. During post MON months, the zooplankton population too exhibited well defined spatial variation. Like PRM and MON, copepoda remained as the most dominant group. It was followed by larval forms at stations R-2, R-3 and R-5 and branchiopoda and gastropoda as the 2nd dominant group at stations R-1 and R-4 respectively. Group wise contributions of major taxa are given here under.

The population density of copepods showed well marked spatial and temporal variation (Table 5). Average numerical abundance of copepods was maximum in March (11946 org./10m^3) and minimum in August (1062 org. /10m^3). Seasonal pooled average population density of copepod was higher during PRM (8083 org./10m^3) followed by POM (4565 org./10m^3) and MON (1927 org./10m^3). Higher population density of copepod during PRM suggested higher secondary productivity. Similar situation was also reported earlier along the Odisha coast [2,11-13]. The occurrence of higher values of copepod density in the zooplankton community corroborates many earlier findings[33,35,40-42]. During the present study, contribution of Copepod to the total zooplankton population ranged from 58-84% (Fig.2). Many workers have also reported almost similar contribution of copepods ranging from 51.82-91.25% in Rushikulya estuary[13], 57.94-89.98% in Bahuda estuary[2], in Chilika lake 42.58-69.69% by Devasundaram and Roy[10], 67.84-94.99% by Naik et al[12] & and 53.5-67.9% in the coastal waters of Bay of Bengal off the Rushikulya estuary[17]. Calanoid copepods contributed 64.0%, 73.7% and 82.2% to total copepod during PRM, MON and POM season respectively. Cyclopoids contributed to about 17.6%, 17.7%, 2.5%, where as harpacticoida contributed to 11.5%, 2.5%, 2.7% corresponding to the PRM, MON and POM seasons respectively. Poicilostomatoida contributed only to about to 6.9%, 6.1% and 12.6% during PRM, MON and POM periods. Calanoid dominance as observed during the present study is common phenomenon in Indian coastal waters.

Monthly analysis showed that Cladoceran was more abundant during January (725 org./10m^3), November (avg. 411 org./10m^3) and March (avg.141 org./10m^3) which coincided with the observations of Della and Venugopal[43]. They were abundant during POM (302 org./ 10m^3) and MON (68 org. /10m^3) period as reported earlier by Naomi et al[44]. Among cladocerans, *Evadne tergestina* was more abundant and with higher average population density of 298 org. /10m^3 during POM season followed by MON (51 org./10m^3) and PRM (4 org./10m^3). The highest population density (58 org./10m^3) of ostracods was encountered in June. Seasonally pooled density of this group varied between 2 (POM) & 24 (PRM) org./10m^3. The seasonal average population density of malacostraca represented by 5 forms namely mysids, cumaceans, euphausiids, amphipods & decapods ranged between 61-110 org./10m^3 with maximum and minimum density observed during PRM and POM respectively.

The protozoa *Acanthometron* sp. occurred only in the month of May with population density of 37 org./10m^3. Highest population density (38 org. /10m^3) of tintinnids was encountered in October followed by March (29 org./10m^3). In other months it was either scarce or absent. Low population size of tintinnids could be due to the use of large mesh size (120µm) plankton net as was reported earlier[45].

The population density of foraminifera ranged from 3 - 87 org./10m^3 and were totally absent during the MON season. Pooled average concentration of this group varied from 19 (PRM) - 26 (POM) org./10m^3 (Table 5). Presence of benthic foraminifera in the plankton collection could be ascribed to their addition from the bottom as a result of upward movement in water column as was reported earlier[46].

Group Hydrozoa was encountered during all the months except in September. Their population density ranged from 1–236 org./10m^3. Maximum seasonal average density of 102 org/10m^3 was noticed during PRM in which hydroidomedusae were 89 org./10m^3. Such higher population density during PRM was also reported from Indian coasts[47]. The peak periods of siphonophores abundance in March and February is in coincidence with the earlier observation in Cochin Backwater[48]. Among the 10 species of siphonophores, *Diphyes dispar* remained as the dominant species contributing 78.4% in PRM, 55.4% in MON and 82.0% in POM of total siphonophore population.

Gastropoda had occurred throughout the year except in May and September. They were more abundant (403 org./10m^3) during December (Table 5). Their population size ranged from 2 - 403 org./10m^3. Seasonally pooled average density varied from 2(MON) - 122 (POM) org./10m^3. Of all the species, C*resis acicula* appeared during greater part of the year and were more conspicuous in December (402 org./10m^3) which resembles with the observation in inshore waters of Karwar[49].

The population size of chaetognaths ranged from 6 - 220 org./10m^3. They were encountered in good numbers in December. Seasonally pooled average values showed that it remained higher during POM season (84 org./10m^3) followed by PRM (34 org./10m^3) and MON (10 org./10m^3) in order. High abundance of chaetognaths during POM was also reported by in the coastal water of Adubidri[39]. Compared with the other groups, Ctenophora appeared with very low percentage with a maximum density of 2 org./10m^3.The population density of Chordates represented by two major classes namely appendicularia and thaliacea ranged from 1-520 org./10m^3 in which *Oikopleura dioica* was more abundant. *Doliolum* sp and *Salpa fusiformis* belonging to thaliacea were found but was in very low percentages.

In total, 23 different larval forms of invertebrates were observed during the study period (Table 4). Larval population showed their maximum density during March (7342 org./10m^3). Average PRM density was 3022 org. /10m^3 followed by POM (507 org./10m^3) and MON (284 org./10m^3). Gastropod veliger, Caridean larvae and fish eggs were dominant in the larval population of PRM, MON and POM respectively. Gastropod veligers were more abundant in March compared to other months. It agrees with the observations made in the inshore waters of Karwar[49]. All the crustacean larvae together contributed 3.8% in POM - 9.0 % in PRM of the total zooplankton density which was high as compared to the earlier report[17]. The other larvae together contributed to about 4.2% in MON to 17.0% during PRM of the total zooplankton density.

Zooplankton density showed positive correlation with DO ($r=0.546$, $p<0.05$), nitrate ($r=0.672$, $p<0.01$) and chlorophyll *a* ($r=0.857$, $p<0.01$) concentration (Table 6). The positive correlation values between zooplankton density and chlorophyll *a* suggested the coexistence of zooplankton community and phytoplankton. Normally the zooplankton density exhibits inverse relationship with phytoplankton. However positive correlations between these two groups are also not very rare as opined by Prasad[50]. Many researchers[40,42] have reported direct relationship between salinity and zooplankton population density. In the present study, however, no definite correlation between these two parameters was observed.

Non-metric multidimensional scaling (MDS) ordinations based on Bray-Curtis[51] similarities of species abundance data were produced to provide a visual representation in a two-dimensional plot of the relative similarities in zooplankton community species composition and abundance at different sampling sites as well as on different sampling occasions. This analysis formed different groups by taking into account of similar species composition (Fig. 3). From the MDS ordination (Fig. 3) it is clear that species composition was unequal during different months as there is no similarity found more than 40%

Table 6. Correlation matrix among different physicochemical and biological parameters

	WT	pH	DO	Salinity	NO_2	NO_3	PO_4	SiO_4	Chl-*a*	Zoo
WT	1									
pH	.184	1								
DO	-0.155	-0.490	1							
Salinity	.629*	.687**	-.590*	1						
NO_2	-0.218	-.525*	.279	-0.340	1					
NO_3	-0.455	-0.259	.240	-.552*	-0.078	1				
PO_4	-0.419	-.640*	.860**	-.712**	.345	.419	1			
SiO_4	-.747**	-0.166	.395	-.583*	.073	.551*	.572*	1		
Chl-*a*	.080	-.544*	.356	-0.342	.042	.522*	.359	.057	1	
Zoo	.099	-0.379	.546*	-0.395	-0.086	.672**	.448	.155	.857**	1

*Correlation is significant 0.05 level, **Correlation is significant 0.01 level

level. September, March, June and January were individually grouped proving their unique species composition, whereas cluster between some months were found irrespective of seasons. This type of poor similarity index could be attributed to the patchy distribution of zooplankton in this area as observed by Omori & Hamner[52]**.** From these results it could be inferred that there is a spatial and temporal heterogeneity in species composition and distribution of zooplankton in this part of the Bay of Bengal.

Table 7. Monthly variations of Univariate diversity indices

Sample	d	J'	H'(loge)	Lambda
Mar	6.76	0.74	3.22	0.08
Apr	5.11	0.65	2.64	0.13
May	4.16	0.70	2.70	0.10
Jun	6.04	0.66	2.69	0.14
Jul	7.20	0.77	3.21	0.06
Aug	5.26	0.70	2.71	0.14
Sep	4.68	0.71	2.74	0.12
Oct	5.39	0.69	2.74	0.14
Nov	6.34	0.66	2.76	0.14
Dec	7.15	0.64	2.80	0.11
Jan	8.32	0.46	2.02	0.22
Feb	8.11	0.78	3.41	0.05

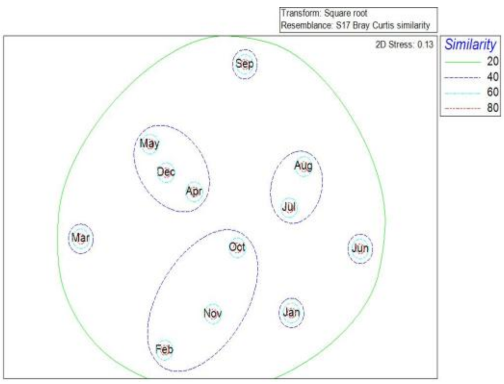

Fig.3.Non-parametric multi-dimensional scaling (MDS) ordination of the square-root transformed zooplankton community of each month

Conclusion

In the present study effort was made to explore the zooplankton diversity as well as to determine current status of zooplankton composition and its population size variation in coastal waters of the Bay of Bengal, off the Rushikulya estuary. It has been found that the faunal composition of zooplankton remained significantly diverse. Copepods have emerged as the most dominant group contributing >50% of total population. Occurrence of low saline copepod species signified estuarine influence on the distribution of plankton community. It further revealed that zooplankton fauna of the region is susceptible to change under the influence of different environmental parameters such as salinity, chlorophyll *a* and nutrients of the ambient medium, rather than salinity resulting heterogeneity in species composition, population size and abundance of zooplankton.

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