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Zooplankton community distribution along offshore transects of some Indian estuaries of east coast: A taxonomic investigation during a summer cruise

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Zooplankton abundance and composition were studied by selecting offshore transects of seven estuaries *viz.* Pennar, Krishna, Godavari, Gosthani, Rushikulya, Devi and Mahanadi along east coast of India during April, 2011. During the study period, sea surface temperature (SST) varied from 27.9°C to 28.3°C with an average of 28.1°C. Salinity varied from 33.0 to 35.0 PSU with an average of 34.5 PSU. Different zooplankton groups belonging to 13 phyla were recorded from seven transects. Copepods dominated the community with 50.5 to 96.8%. Calanoids, namely *Paracalanus parvus, P. aculeatus, Temora turbinata* were common in all the transects studied. The Shannon's diversity index (H′) was found highest in Pennar (2.666) and lowest in Godavari transect (1.785). From cluster analysis and non-parametric multidimensional scaling (nMDS), it is observed that the species composition was changing from north to south of the study area.

[**Keywords:** Zooplankton, copepods, community structure, nMDS, Bay of Bengal]

Introduction

Zooplankton are the secondary producers of the ocean. They play an important role in forming a linkage between primary producers (phytoplankton) and higher trophic levels[1,2]. Few zooplankton species could be used as potential indicators of pollution[3] and climate change (global warming)[4].

From a hydrographical point of view the east coast of India is of particular interest due to influx of large amount of freshwater into the Bay via the major rivers *viz*. Krishna and Godavari in south and Mahanadi and Ganges in North. The surface currents of the coast reverse their directions semiannually[5]. Circulation in Bay of Bengal during winter is anti-cyclonic and cyclonic during summer[6]. These opposite currents also influence the hydro-biological conditions in the inshore waters to a marked extent[7]. A thorough study of literature on zooplankton in Bay of Bengal revealed that most of the works are limited either to estuaries, backwaters or coastal waters [8-13] and some on offshore waters[14-16]. Hence, the current study was focused to bring out the community structure of zooplankton along offshore transects of seven major estuaries along east coast of India.

Material and Methods

The Bay of Bengal is a marginal sea of the Indian Ocean. It is always under the influence of monsoons, tropical cyclones and depressions. In the present investigation, sampling was carried out along the offshore transects of seven estuaries *viz.* Pennar, Krishna, Godavari, Gosthani, Rushikulya, Devi and Mahanadi (Fig. 1). These rivers drain huge quantities of freshwater and sediments to the Bay especially in monsoon periods and thus play a major role in sediment dynamics, nearshore current pattern, surface circulation, fishery diversity and productivity of the coastal water[17].

The survey was carried out onboard MoES research vessel CRV '*Sagar Paschimi*' (Cruise No. 09/11) during 1-8 April 2011 jointly by Integrated Coastal and Marine Area Management (ICMAM), Chennai and Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. Samples were collected from the

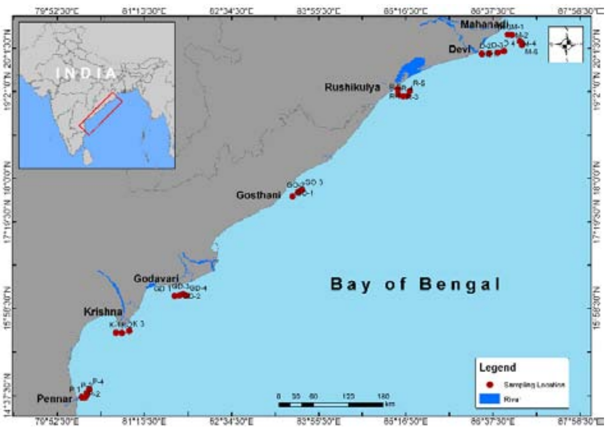

Fig. 1. Map showing the sampling sites along the east coast of India

Table 1. Sampling period, location and depth of transects/stations

Transect	Transect Code	Station Code	Date of sampling	Time	Position		Depth (m)
					Lat(N)	*Long(E)*	
Pennar	T-1	P-1	02/04/2011	10:30	14°36.16′	80°15.13′	25
	T-1	P-2	02/04/2011	11:40	14°36.15′	80°18.39′	50
	T-1	P-3	02/04/2011	13:30	14°39.77′	80°19.72′	84
	T-1	P-4	02/04/2011	14:20	14°43.31′	80°22.14′	200
Krishna	T-2	K-1	03/04/2011	10:30	15°36.16′	80°46.93′	25
	T-2	K-2	03/04/2011	11:45	15°35.81′	80°52.48′	50
	T-2	K-3	03/04/2011	13:00	15°37.46′	80°59.37′	100
Godavari	T-3	GD-1	04/04/2011	11:00	16°10.09′	81°41.54′	25
	T-3	GD-2	04/04/2011	12:00	16°10.64′	81°45.98′	50
	T-3	GD-3	04/04/2011	13:00	16°12.06′	81°49.37′	100
	T-3	GD-4	04/04/2011	14:00	16°10.60′	81°52.30′	200
Gosthani	T-4	GO-1	05/04/2011	10:30	17°43.10′	83°31.20′	51
	T-4	GO-2	05/04/2011	11:45	17°46.98′	83°36.25′	50
	T-4	GO-3	05/04/2011	13:00	17°49.27′	83°39.64′	50
Rushikulya	T-5	R-1	06/04/2011	10:00	19°23.48′	85°08.90′	25
	T-5	R-2	06/04/2011	11:00	19°18.44′	85°09.15′	52
	T-5	R-3	06/04/2011	12:00	19°16.56′	85°13.81′	66
	T-5	R-4	06/04/2011	13:00	19°16.88′	85°17.50′	86
	T-5	R-5	06/04/2011	14:15	19°21.63′	85°20.21′	64
Devi	T-6	D-1	07/04/2011	10:20	19°56.29′	86°27.02′	25
	T-6	D-2	07/04/2011	11:30	19°56.83′	86°33.96′	37
	T-6	D-3	07/04/2011	12:45	19°57.48′	86°41.81′	48
	T-6	D-4	07/04/2011	14:10	19°59.05′	86°47.65′	65
Mahanadi	T-7	M-5	08/04/2011	10:00	20°04.73′	87°04.40′	100
	T-7	M-4	08/04/2011	11:10	20°08.05′	87°02.47′	53
	T-7	M-3	08/04/2011	12:20	20°14.06′	86°55.19′	41
	T-7	M-2	08/04/2011	13:15	20°14.06′	86°55.19′	29
	T-7	M-1	08/04/2011	14:10	20°14.38′	86°51.29′	24

seven offshore transects comprising 28 stations (Table 1).

Sea surface temperature using thermometer (Brannan Digital) (±0.1ºC), transparency using Secchi disc, pH using digital pH reader (±0.1) (Hanna HI98127) and salinity using Refractometer (ATAGO) were recorded at each station. Water samples at each station were analyzed for dissolved oxygen (DO) following Winkler's titration method[18]. Each of these parameters was subjected to single factor ANOVA to find out any significant variation among the offshore transects.

Zooplankton samples were collected at each station from surface water by horizontal hauling of zooplankton net (mouth area $0.25m^2$, mesh size of 300µm) for 5 minutes and preserved in 5% formaldehyde. A digital flow meter (HydroBios) was used to determine the volume of water filtered. In the laboratory, the zooplankton samples were sub-sampled with the help of a Folsom plankton splitter for quantitative and qualitative analysis. An aliquot of the sample was taken from the sub-sample and observed under an inverted microscope (Cippon; Model No.21033) for identification and counting. The numerical abundance values were represented in Nos./$100m^3$. Relative abundance was computed from total density and the density of each group. Different groups/species of zooplankton were identified referring standard literatures[19-22].

Zooplankton community structures were analyzed using standard univariate statistical indices, *viz.*, Margalef's species richness (d), Shannon's diversity index (H′), Simpson's dominance index (D) and Pilou's evenness index (J′). Multivariate statistics such as non-parametric multi-dimensional scaling (nMDS) and cluster analysis was applied on the abundance data employing PRIMER software (Version 5)[23].

The statistical bio-indices are calculated as follows:

Margalef's species richness [d][24] = $(S - 1)/\ln N$

S = number of taxa
N = number of individuals.

Shannon's diversity index [H'][25]

$$H' = \sum_{i=1}^{s} - (P_i * \ln P_i)$$

P_i = fraction of the entire population made up of species i

S = number of species encountered
∑ = sum from species 1 to species S

Pilou's species evenness [J'][26]

J' = H' / In S
H' = Shannon's diversity index
S = total number of species in the sample

Simpson's dominance index [D][27]

$D = \sum (Pi)^2$

P_i = fraction of the entire population made up of species i

Results

During the course of this study, water transparency ranged from 6 m to 45 m with an average of 19.12m. In Mahanadi transect, transparency reading was recorded from 10m to 17m with a mean value of 15m (Table 2). Water was found to be more transparent at Krishna and less at Pennar.

Sea surface temperature (SST) varied from 27.9°C to 28.3°C with an average of 28.1°C. Lowest and highest SSTs were observed at Rushikulya transect. The pH ranged from 7.90 to 8.10 with an average of 8.03 in all sampling transects. Maximum pH (8.1) was recorded in Krishna and Devi and the minimum (7.9) was in Mahanadi transect (Table 2). Salinity varied from 33.0 to 35.0 PSU with an average of 34.5 PSU. Lower salinity values are obtained in Northern transects. Dissolved oxygen ranged from 6.40 to 8.90 mg/L with an average of 7.58 mg/L in all transects.

Different zooplankton groups belonging to 13 phyla were recorded from 7 transects (28 stations). Copepods dominated the community with 50.5% to 96.8% (Table 3). Transectwise variations in the relative abundance of zooplankton are shown in Figure 2. Zooplankton abundance peaked at station M-5 (228800 Nos./100m^3) of Mahanadi transect and the lowest number was recorded at station GD-1 (9819 Nos./100m^3) of Godavari transect. Transectwise highest average abundance was recorded in Mahanadi transect (90208 Nos./100m^3) and lowest average in Krishna transect (51022 Nos./100m^3). Average abundance of zooplankton excluding copepods was observed higher in Pennar (23548 Nos./100m^3), Rushikulya (18529 Nos./100m^3) and Devi transect (15550 Nos./100m^3), and the lowest was from Gosthani transect (6267 Nos./100m^3).

A total number of 132 taxa (106 species and other larval forms) of zooplankton were identified from the entire study. The relative abundance of dominant zooplankton groups are presented in Figure 2.

The tintinnids that comes under microzooplankton is represented by the genus *Tintinnopsis* with 2 species and *Codonellopsis* with one species. Lower percentage of composition of tintinnids was due to use of large mesh size (300µm) of plankton net.

Siphonophore were distributed throughout the whole transects and their contribution ranged from 0.1% to 17.3%. Lowest average relative abundance was recorded at Krishna whereas highest at Devi. Three families i.e. Agalmatidae, Diphyidae and Abylidae represented the siphonophores. Among Diphyidae, the *Diphyes dispar* was abundant in terms of density and

Table 2. Physico-chemical parameters (average in brackets) along offshore transects of seven estuaries during summer (April 2011)

	T-1	T-2	T-3	T-4	T-5	T-6	T-7
Transparency (m)	6.0-40.0 (24.2)	15.0-45.0 (26.6)	8.0-35.0 (23.7)	12.0-21.0 (17.0)	13.0-17.0 (16.2)	11.0-19.0 (11.0)	10.0-17.0 (15.0)
Water temperature (°C)	27.9-28.3 (28.1)	28.2-28.3 (28.3)	28.4-29.1 (28.9)	28.5-28.8 (28.7)	27.9-29.8 (29.1)	28.1-28.3 (28.2)	27.9-28.3 (28.1)
pH	8.0-8.1 (8.03)	8.1-8.1 (8.1)	8.0-8.1 (8.05)	8.0-8.0 (8.0)	8.0-8.1 (8.06)	8.1-8.1 (8.1)	7.9-8.1 (8.04)
Salinity (PSU)	34.0-35.0 (34.5)	33.0-35.0 (34.0)	34.0-35.0 (34.5)	34.0-35.0 (34.6)	33.0-35.0 (34.2)	35.0-35.0 (35.0)	33.0-34.0 (33.5)
DO (mg.L^{-1})	6.90-8.60 (7.58)	6.80-7.40 (7.13)	6.80-8.20 (7.63)	7.60-8.10 (7.83)	7.20-8.90 (8.0)	6.40-7.80 (7.30)	6.40-7.60 (7.10)
Phyto Abundance (cells/L)	19500-29064 (24320)	19044-39236 (26680)	8160-12120 (9480)	9760-21900 (14927)	10160-29760 (17280)	15840-27600 (22640)	11920-53967 (24521)
Zooplankton Abundance (Nos./100m^3)	10004 - 150933 (59461)	26320 - 90667 (51022)	9819 - 191034 (57373)	16400 - 134800 (88400)	15026 - 169947 (74868)	18933 - 91467 (53500)	33439 - 228800 (90208)

distribution at all transects except in Krishna and Gosthani. *Eudoxides mitra* belonging to the same family were noticed from Krishna, Gosthani and Devi. Other species of siphonophore were sporadic in their distribution.

In all transects of study, the hydroidomedusae varied from 0 - 7%. *Liriope tetraphylla* was the dominant species of hydroidomedusae and distributed in all transects. *Podocoryne* sp., *Phialella quadrata, Aglaura hemistoma* and *Aequorea vitrina* were sporadic in their distribution. Regarding Cladocera (Branchiopoda), they could not be observed in Godavari and Devi. Relative abundance of Cladocera contributed up to 8.5%. It occupied second order of dominancy in Pennar and Krishna whereas third order of dominancy at Gosthani.

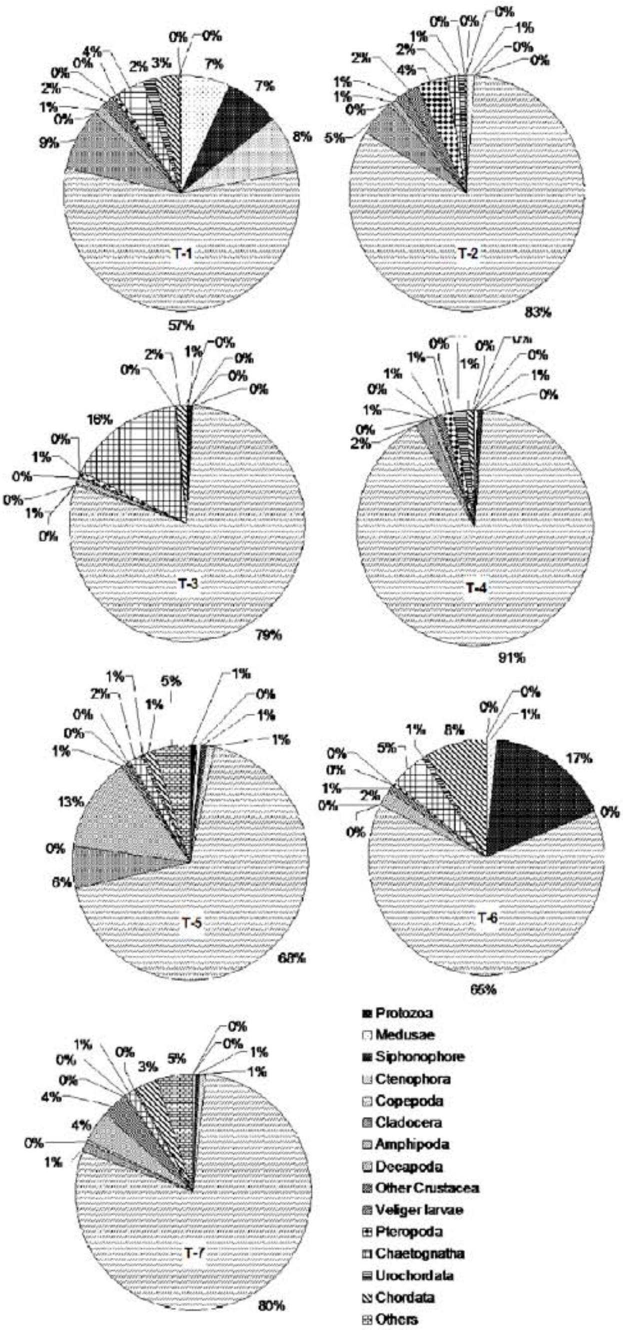

Fig. 2. Composition of zooplankton in sampling transects

Chaetognaths occupied fourth position in order of dominancy in Pennar and Krishna. In Rushikulya and Mahanadi, they occurred with very low percentage. The collection included mainly two species of arrow worms i.e. *Sagitta enflata* and *Sagitta bipunctata*. A fairly high abundance of Decapoda including *Lucifer hanseni, Lucifer penicillifer* and *Sergestes* sp. were noticed in Pennar, Gosthani, Rushikulya, Devi and Mahanadi whereas high abundance of Amphipoda with the genus *Hyperia* sp. were recorded in Krishna and Godavari transects.

Pteropods comprised up of *Creseis acicula*, *Creseis sp*. and *Hyalocylis striata* during the study. The gastropods were commonly distributed in all transects except Mahanadi with maximum contribution 4.1% to the zooplankton density. *Oikopleura* spp. is an important genus of Larvaceans in the Bay of Bengal. Two species i.e. *Oikopleura parva* and *Oikopleura dioica* were recorded.

Meroplankton constitutes a major fraction of zooplankton community in tropical seas. Different meroplankton were recorded in the entire study.

Copepod community

The population density of copepod showed well marked spatial variation and it ranged from 7104 Nos./100m^3 (off Pennar) to 219840 Nos./100m^3 (off Mahanadi). In the entire study copepod were found to represent by 64 species, belonging to 22 families and 4 orders, out of which 44 species were from calanoida. Cyclopoida formed the second dominant group, which was represented by 13 species. Order harpacticoida and poecilostomatoida were represented only by 5 and 2 species respectively. Calanoida contributed up to 82%, cyclopoida copepod up to 17% and harpacticoida up to 1% of total copepods. Among the calanoida, the species

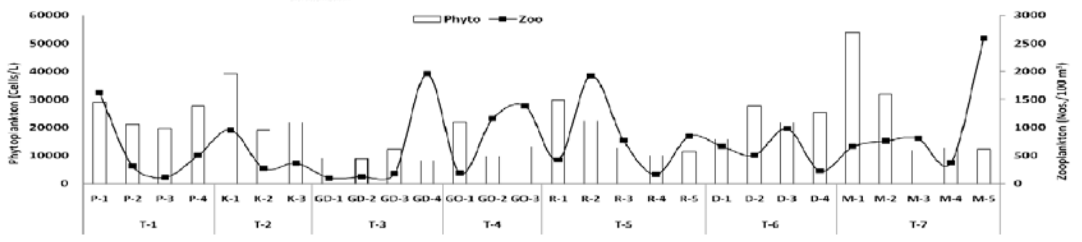

Fig. 3. Variation of zooplankton abundance with phytoplankton

Table 3. Distribution and abundance (Nos./100m^3) of zooplankton along offshore transects of seven estuaries during summer (April 2011)

Name of the Species/Taxa	T-1	T-2	T-3	T-4	T-5	T-6	T-7
PROTOZOA							
Acantharia							
Acanthometron sp.	0	0	0	0	349	0	0
Ciliata							
Tintinnopsis tocantinensis (Kofoid and Campbell, 1929)	0	0	100	0	0	0	0
Codonellopsis ostenfeldii Kofoid & Campbell, 1929)	0	0	100	0	0	0	0
Tintinnopsis nordqvisti (Brandt, 1906)	0	0	100	0	0	0	0
Foraminifera							
Globigerina bulloides (d'Orbigny, 1826)	0	0	0	0	307	0	0
CNIDARIA							
Hydroidomedusae							
Cladonema sp.	0	0	0	0	0	67	0
Podocoryne sp.	0	0	0	133	0	0	0
Phialella quadrata (Forbes, 1848)	44	0	0	0	0	133	0
Liriope tetraphylla (Chamisso and Eysenhardt, 1821)	3896	523	19	0	402	467	213
Aglaura hemistoma (Peron and Lesueur, 1810)	2	0	0	0	0	100	0
Aequorea vitrina (Gosse, 1853)	267	0	0	0	0	0	0
Siphonophorae							
Agalma elegans (Sars,1846)	403	0	0	0	0	667	0
Sulculeolaria turgida (Gegenbaur, 1853)	87	0	0	0	0	0	0
Sulculeolaria sp.	0	0	0	400	0	0	64
Diphyes bojani (Eschsoltz, 1829)	10	0	37	0	0	0	0
Diphyes dispar (Chamisso and Eysenhardt, 1821)	1609	0	149	0	889	1600	533
Lensia subtilis (Chun, 1886)	87	0	0	0	0	0	0
Lensia subtiloides (Lens and van Riemsdijk, 1908)	0	0	0	0	0	2517	0
Eudoxoides mitra (Huxley, 1859)	0	48	0	400	0	5550	0
Muggiaea sp.	2552	0	0	0	0	0	0
Bassia bassensis (Quoy and Gaimard,(1833) 1834)	0	48	0	133	0	0	0
CTENOPHORA							
Pleurobrachia pileus (O. F. Müller, 1776)	4970	0	0	0	339	0	807
Beroe sp.	0	48	0	0	392	0	0
ANNELIDA							
Polychaete larva	0	0	0	133	85	0	0
ARTHROPODA							
Copepoda → Calanoida							
Nannocalanus minor (Claus, 1863)	448	11904	0	0	5852	467	3284
Mesocalanus tenuicornis (Dana, 1849)	0	0	0	0	455	1333	0
Subeucalanus subcrassus (Giesbrecht, 1888)	0	143	0	0	0	533	0
Eucalanus sp.	4032	0	0	0	0	267	1128
Eucalanus attenuatus (Dana, 1849)	543	0	1107	0	3153	0	0
Acrocalanus gracilis (Giesbrecht, 1888)	0	0	0	0	2265	0	0
A. longicornis (Giesbrecht, 1888)	1344	0	0	4133	7259	550	1557
A. gibber (Giesbrecht, 1888)	1275	0	0	6800	0	1250	6311
Paracalanus aculeatus (Giesbrecht, 1888)	1600	8685	14757	0	8593	12283	26040
P. parvus (Claus, 1863)	1416	0	20347	30267	12169	2267	21180
Paracalanus sp. (Boeck, 1865)	480	0	0	0	0	0	0
Euchaeta marina (Prestandrea, 1833)	0	116	0	0	169	0	0
Euchaeta indica (Wolfenden, 1905)	0	0	0	0	0	0	10
Scolecithrix danae (Lubbock, 1856)	0	0	0	0	0	700	0
Centropages orsini (Giesbrecht, 1889)	107	1040	0	0	0	0	0
C. furcatus (Dana, 1849)	299	0	0	0	0	350	0
Centropages tenuiremis (Thompson & Scott, 1903)	1024	0	0	0	0	0	0
Centropages dorsispinatus (Thompson & Scott, 1903)	80	0	0	0	0	0	0
Centropages sp. (Krøyer, 1849)	533	0	938	0	0	0	0
Pseudodiaptomus aurivilli (Cleve, 1901)	0	0	0	0	0	67	3497

P. serricaudatus (T.Scott, 1894)	0	0	0	0	0	0	3691
Temora discaudata (Giesbrecht, 1889)	3051	3600	1423	0	0	3000	0
T. turbinata (Dana, 1849)	6682	8682	446	3200	0	2517	2428
Metacalanus aurivilli (Cleve, 1901)	0	0	0	0	0	0	0
Candacia discaudata (A.Scott, 1909)	0	0	0	133	0	0	0
Candacia sp. (Dana, 1846)	0	0	0	0	0	67	383
Paracandacia simplex (Giesbrecht, 1889)	0	0	0	0	0	983	0
Candacia catula (Wolfenden, 1905)	0	0	0	0	0	600	0
Labidocera acuta (Dana, 1849)	0	543	865	0	392	600	0
Labidocera minuta (Giesbrecht, 1889)	0	48	0	0	0	0	0
Pontella danae (Giesbrecht, variety *ceylonica* Thompson & Scott, 1903)	0	143	0	133	402	0	0
P. securifer (Brady, 1883)	133	0	0	0	0	0	0
Calanopia minor (A. Scott, 1902)	0	380	389	0	0	4933	768
Calanopia elliptica (Dana, 1846, 1849)	0	0	248	0	0	0	0
Calanopia thompsoni (A. Scott, 1909)	16	0	0	0	0	0	0
Pontellina plumata (Dana, 1849)	53	116	0	0	0	667	0
Acartia erythraea (Giesbrecht, 1889)	1745	3315	0	6533	3259	2083	3001
Acartia centrura (Giesbrecht, 1889)	128	0	0	0	0	0	1535
Acartia spinicauda (Giesbrecht, 1889)	0	95	0	0	0	700	320
Acartia danae (Giesbrecht, 1889)	0	143	0	0	0	233	998
Acartia sp. (Dana, 1846)	1067	0	0	1867	0	0	0
Tortanus barbatus (Brady, 1883)	0	0	0	2933	5164	0	0
Pleuromamma xiphias (Giesbrecht,1889)	0	0	0	0	0	0	361
Pleuromamma sp. (Giesbrecht in G & Schmeil, 1898)	0	0	0	0	0	733	0
Copepoda → Cyclopoida							
Corycaeus catus (F. Dahl, 1894)	213	1964	0	133	519	0	1235
Corycaeus longistylis (Dana, 1849)	320	0	3516	0	0	0	0
Corycaeus sp. (Dana, 1845)	1697	0	0	0	0	200	0
Farranula gibbula (Giesbrecht, 1891)	0	0	0	0	307	0	0
Copilia quadrata (Dana, 1849)	3117	0	3012	14533	0	67	0
Farranula curta (Farran, 1911)	1344	116	0	0	349	0	0
Corycaeus typicus (Kroyer, 1849)	0	0	0	2800	190	0	0
Oithona brevicornis (Giesbrecht, 1891)	0	0	0	0	0	0	896
O. spinirostris (Claus, 1863)	0	0	0	0	0	67	0
Oithona sp.	53	0	0	0	0	0	617
Oncaea venusta (Philippi, 1843)	725	2036	0	8667	1725	0	0
Oncaea conifera (Giesbrecht, 1891)	448	0	0	0	3481	0	0
Oncaea sp.	640	0	0	0	0	0	0
Copepoda → Poecilostomatoida							
Sapphirina ovatolanceolata (Dana, 1849)	0	0	0	0	0	233	960
Sapphirina nigromaculata (Claus, 1863)	0	0	0	0	0	0	639
Copepoda → Harpacticoida							
Microsetella norvegica (Boeck, 1864)	0	0	0	0	0	67	0
M. rosea (Dana, 1848)	213	0	0	0	635	0	0
Macrosetella gracilis (Dana, 1847)	0	551	0	0	0	0	0
Clytemnestra scutellata (Dana, 1849)	0	238	0	0	0	67	0
Euterpina acutifrons (Dana, 1848)	1087	0	0	0	0	67	832
Cladocera							
Evadne nordmanni (Loven, 1836)	0	2053	0	400	3989	0	576
Evadne tergestina (Claus, 1877)	853	618	0	1067	0	0	0
Penilia avirostris (Dana, 1849)	4572	0	0	400	804	0	960
Ostracoda							
Macrocypridina castanea (Brady,1897)	0	0	0	0	21	0	0
Conchoecia elegans (Sars,1865)	0	0	0	0	0	0	510
Amphipoda							
Hyperia sp.	0	231	130	0	42	0	192
Isopoda							
Isopod larvae	0	0	0	0	0	67	0
Decapoda							

Lucifer hanseni (Nobili, 1905)	299	116	0	133	8804	317	3049
*Lucifer penicillife*r (Hansen, 1919)	0	0	0	0	0	400	0
Sergestes sp.	0	0	0	267	0	0	0
Brachyuran megalopa larva	149	116	0	0	0	0	0
Brachyuran zoea larvae	343	116	534	133	190	267	384
Caridean larvae	0	0	19	0	106	0	0
Mysis larvae	0	0	0	0	0	0	1301
Protozoea of *Lucifer*	0	0	0	133	1397	133	787
Protozoea of *Penaeus indicus*	0	0	0	0	0	133	0
Zoea larva of *Elamen* sp.	0	0	56	0	0	0	0
Zoea larva of porcellanid crab	0	0	0	0	42	0	0
Zoea of *Emerita* sp.	0	0	0	0	0	0	64
Other Crustaceans							
Larvae of euphausiid	0	0	0	133	0	67	0
Alima larva of *Squilla*	165	116	19	267	0	0	533
Antizoea stage of stomatopod	133	0	0	0	0	0	0
Barnacle naulpii	214	0	74	0	148	133	1319
Copepod nauplii	0	604	0	0	0	0	64
Cyprid larvae	651	0	0	0	476	417	213
Pycnogonida	0	0	19	0	0	0	0
MOLLUSCA							
Veliger larva	160	1111	74	667	148	0	299
Pteropoda	0	0	0	0	0	0	0
Creseis acicula (Rang, 1828)	267	2098	298	1333	190	117	0
Creseis sp.	0	95	0	0	0	0	0
Hyalocylis striata (Rang, 1828)	0	0	0	0	0	133	0
ECHINODERMATA							
Ophiopluteus larva	149	0	0	0	0	0	0
CHAETOGNATHA							
Sagitta bipunctata (Quoy & Gaimard, 1828)	2240	0	0	0	910	2250	0
Sagitta enflata (Grassi, 1881)	256	862	9579	0	593	667	1321
PHORONIDA							
Actinotroch larvae	0	0	0	0	4106	0	4736
BRACHIOPODA							
Brachiopod larvae	0	0	0	0	0	67	107
BRYOZOA							
Cyphonautes larva	0	0	0	0	0	0	320
UROCHORDATA							
Larvacea							
Oikopleura parva (Lohmann, 1896)	565	0	37	1333	413	67	320
Oikopleura dioica (Fol, 1872)	179	0	0	133	0	67	0
Oikopleura sp.	0	333	0	0	0	0	0
Thaliacea							
Doliolum sp.	400	0	0	133	85	233	0
Salpa fusiformis (Cuvier, 1804)	0	95	0	0	0	200	0
CHORDATA							
Fish eggs	1909	211	627	933	1016	4833	3092
Fish larvae	175	0	267	0	0	0	64

Temora turbinata dominated in Pennar, *Nannocalanus minor* in Krishna, *Paracalanus parvus* in Godavari, Gosthani & Rushikulya, *Paracalanus aculeatus* in both Devi and Mahanadi. The family Corycaeidae belonging to the order cyclopoida was dominant in all transects except in Rushikulya where Oncaeidae remained dominant. Among the Corycaeidae, *Copilia quadrata* was present at Pennar and Gosthani, *Corycaeus catus* was found from 2 transects i.e. Krishna and Mahanadi, *Corycaeus longistylis* was encountered only in Godavari and *Corycaeus* sp. only at Devi. *Oncaea conifera* belonging to Oncaeidae was noticed from Rushikulya. A very minor contribution was made by the harpacticoida and poiecilostomatoida. Species such as *Microsetella norvegica* (Devi), *Microsetella rosea* (Pennar and Rushikulya), *Macrosetella gracilis* (Krishna), *Clytemnestra scutellata* (Krishna and Devi), *Euterpina acutifrons* (Pennar, Devi and Mahanadi), *Sapphirina ovatolanceolata* (Devi and

Mahanadi) and *Sapphirina nigromaculata* (Mahanadi) were observed.

Discussion

Temperature is one of the most important physical parameters that influence the hydrography and distribution of biota in all types of coastal ecosystems. Both temperature and salinity considerably affect the bio-geochemical cycling of certain elements[28]. There was no particular trend observed in the surface water temperature among sampling sites during the study period. Along the Western Bay, previous study shows that the average salinity was 33.7 PSU up to 16°N in the surface layer but decreased northwards reaching as low as 29.6 PSU at 19°N[29,30]. ANOVA performed on the dataset, revealed significant variability ($P<0.05$) in water temperature among the transects. The variation might be due to the difference in sampling time. Rest of the parameters pH, salinity, DO did not vary significantly from one transect to another. Thus in general environmental parameters of the seven estuarine offshore transects were similar to each other. The higher water transparency in southern side of study area (Pennar, Krishna & Godavari transects) indicates more riverine influence in northern side than southern side. Transparency was more at higher depths in all transects (Table 2).

Lowest value of dissolved oxygen was observed in Mahanadi transect followed by Pennar. Lower values might be due to decrease in air-to-sea oxygen flux and photosynthesis rate[31]. But as a whole the recorded range of DO was 6.4 - 8.9 mg/L for all transects. Highest value (8.9 mg/L) was recorded in Rushikulya which is in accordance with the earlier observations[32].

The spatial distribution of zooplankton species and community structure was dynamic and changeable along the whole transect. Analysis of variance showed no significant variation in abundance among transects. Total number of species (106) belonging to different groups from all transects represent the zooplankton community of the area. Like other zoooplankton studies in the Bay[15] and nearby seas[33,34], present observation of zooplankton composition also highlights the dominancy of copepods particularly the calanoid forms. Among all the groups/taxa, copepod was not only the dominant one but also well distributed all along the offshore transects. Occurrence of higher values of copepod among the other zooplankton in transects corroborates many earlier findings[35,36]. Calanoida copepod dominated over other groups in the whole transects which may be due to their continuous breeding behavior, quick larval development and their well adaptation to the widely changing environmental conditions[37,38]. Copepoda, being the dominant component of the zooplankton community, the species diversity is used as an index in all biological monitoring studies to characterize the water quality[39]. Copepoda are known to select preferred habitats and hence their distribution may vary with species[40]. Abundant copepods in the transects were namely *Paracalanus parvus, P. aculeatus, Temora turbinata, Nannocalanus minor, Acrocalanus gracilis, A. gibber, Temora discaudata, Acartia erythraea, Copilia quadrata, Oncaea venusta*. Along east coast of India, Nair et al. (1981)[15] has observed the abundance of *Acrocalanus similis, Paracalanus parvus, Eucalanus monachus, Canthocalanus pauper, Eucalanus crassus, Euchaeta marina, Temora turbinata, Eucalanus subcrassus, Undinula vulgaris, Paracalanus aculeatus* etc. In this study, all the species were not encountered as above; it might be because of larger geographical area studied by Nair et al. (1981)[15]. Other calanoids, cyclopoids and harpacticoids were also well represented in the communities. Wide distribution of a number of zooplankton species off the estuarine transects might be due to the unique nature of water

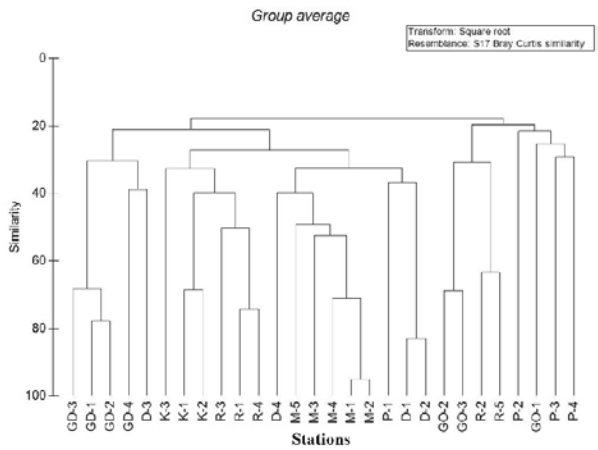

Fig. 4. Hierarchical tree grouping the stations according to zooplankton composition

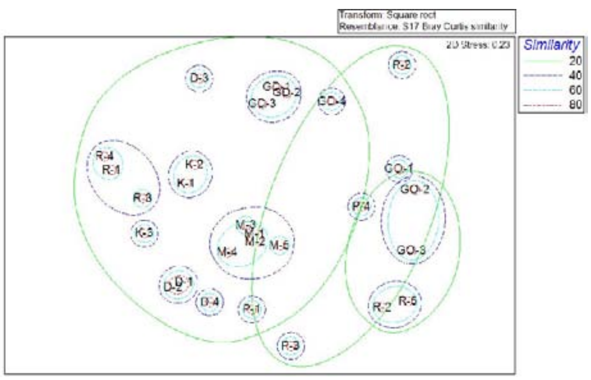

Fig. 5. nMDS plot showing station groups according to zooplankton composition of the study area

quality. In terms of numbers, *Paracalanus parvus* was the most abundant calanoid present all along the east coast.

Analysis of variance also indicated non-significant variation among different sampling transects for zooplankton abundance excluding copepods. *Liriope tetraphylla* was the dominant species of hydroidomedusae and observed in all transects. Similar observation in the Indian Ocean was also reported by Vanncci and Navas (1973)[41]. Their abundance in the collection was affected by the geographic distribution of the sampling sites, mostly oceanic and far from shoreland. The presence of more number of meroplankters could be due to the contribution made by estuarine species from the estuary through tidal incursion.

Regardless the trend of similar phytoplankton abundance (unpublished data) in some transects, the zooplankton numbers varied in the transects (Fig. 3). This shows that the zooplankton population survived on food source other than phytoplankton[42]. This further indicates the possible existence of alternative food chain (through microzooplankton) and the importance of microbial loop in the area. In oligotrophic open ocean waters of the Arabian Sea, Madhupratap et al. (2001)[30] and Smith and Madhupratap (2005)[34] have discussed the existence of such a microbial loop.

Diversity index is intended to measure the biodiversity of an ecosystem. In general, such indices facilitate the understanding, conservation and utilization of living resources by creating a single annotated index of biological collections[43]. Average Margalef's species richness (d) was found highest in Pennar (4.145) followed by Devi (3.380), Mahanadi (3.097) and lowest in Gosthani transect (2.278) (Table 4). Analysis of variance results showed no significant variation of Margalef's index in different transects. The average Shannon's diversity index (H´) was highest in Pennar (2.666) and lowest in Godavari transect (1.785). The greater number of species diversity was observed in Pennar which showed that the individuals in the community were distributed more equitably (J´=0.843) and the Simpson's dominance index is the lowest (0.098). This might be due to better and stable environment off Pennar.

Non-parametric MDS and cluster analysis were applied to know if there is any difference in species composition among stations and transects and if so then how far they were different. These analyses (Fig. 4 and Fig. 5) formed different groups by taking into account of similar species composition. The composition of zooplankton between M1 and M2 is more alike. D1 and D2 exhibited more than 80% of similarity. Similarly GD1 and GD2 are close to about 80% of similarity. All the stations (M1, M2, M3, M4 and M5) of Mahanadi transect formed a group having 40% similarity. Like this the stations of different transects Godavari, Rushikulya, Gosthani, Krishna, Devi formed different groups. The formation of different groups is clearly depicted in nMDS ordination plot (Figure 5). In the nMDS ordination, the outer stations (D3, D4, K3, P4, GD4) of some transects remained different from the other stations. This indicates their species composition was different from their near shore stations. Individual stations (P1, P3, GO1, D3 etc) separated out from the group may be patchy distribution of zooplankton[44]. From this study it can be inferred that there is a spatial differentiation in species composition from north to south in the western Bay of Bengal region.

Table 4. Zooplankton community structure along offshore transects of seven estuaries during summer (April 2011)

Transects	Margalef's index (d)	Shannon's diversity index (H')	Evenness index (J')	Simpson's dominance index (D)
T-1	2.423 - 6.729 (4.145)	2.327 - 2.956 (2.666)	0.834 - 0.853 (0.843)	0.072 - 0.123 (0.098)
T-2	2.496 - 3.229 (2.925)	2.205 - 2.270 (2.239)	0.736 - 0.785 (0.766)	0.136 - 0.157 (0.145)
T-3	1.324 - 3.354 (2.555)	1.725 - 1.828 (1.785)	0.645 - 0.719 (0.678)	0.229 - 0.265 (0.248)
T-4	1.421 - 3.333 (2.278)	1.696 - 2.517 (2.125)	0.707 - 0.871 (0.786)	0.114 - 0.252 (0.173)
T-5	1.960 - 3.006 (2.455)	1.943 - 2.352 (2.113)	0.706 - 0.848 (0.758)	0.138 - 0.215 (0.175)
T-6	2.200 - 4.746 (3.380)	2.237 - 2.746 (2.522)	0.807 - 0.843 (0.828)	0.107 - 0.149 (0.119)
T-7	2.586 - 3.410 (3.097)	1.929 - 2.743 (2.397)	0.633 - 0.932 (0.786)	0.077 - 0.222 (0.143)

Minimum-Maximum (Average)

Conclusion

Under similar environmental conditions in all offshore transects of Western Bay of Bengal, alteration in community structure is inevitable. Similar type of change in phytoplankton community structure was also observed in the same transects (Unpublished data of the same cruise). The light penetration, ambient temperature and the local prevailing environment might be the deciding factors for such alteration in species composition.

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