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Distribution of meiobenthos off Kakinada Bay, Gaderu and Coringa estuarine complex

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Abstract
The data presented in the paper is derived from observations made based on 144 samples collected from Kakinada Bay, Gaderu and Coringa estuarine complex (Lat. 16º 51' to 17º 00' N and Long 82º 14' to 82º 22' E). Observations on the physico-chemical characteristics of the sea water (dissolved oxygen and salinity), % organic matter and mean particle diameter (MPD) of the sediment were made from the study area. In this study, it was observed that the sediment texture was sandy clay in the North Bay, South Bay and Gaderu, whereas silty in Coringa. The meiobenthic abundance was dominated by Nematoda (37%), Copepoda (15.0%), Foraminifera (13.1%), Polychaeta (9.9%), Ostracoda (6.2%), Archiannelida (2.0%), Kinorhyncha (2.4%) and others (14.3%). The dominant species among the Nematoda, Copepoda, Foraminifera, Polychaeta, Ostracoda, Kinorhyncha, and Archiannelids were identified upto species level. Numerically, meiobenthos abundance varied appreciably in the North Bay, South Bay, Gaderu and Coringa waterways showed considerable seasonal variations, in both occurrence and abundance. The CCA analyses showed that salinity along with sediment texture influenced the meiobenthic abundance in the Kakinada Bay, Gaderu and Coringa estuarine complex. It is recommended to include meiobenthic community level analysis in future environmental studies for a better understanding of coastal marine ecosystems.

Keywords: *Hydrography, sediment texture, meiobenthos abundance, dominant species, Kakinada estuarine complex, east coast of India*

Introduction

Meiobenthos are the major metazoan component of benthic ecosystem and its production is equal or higher than macrobenthos in shallow waters to deep sea (Gerlach, 1971; Platt and Warwick, 1980; Heip *et al.,* 1985; Coull, 1999). Meiobenthos facilitates biomineralization of organic matter (OM), and enhances nutrient regeneration (McIntyre, 1969; Feller and Warwick, 1988; Montagna, 1995). Estimation of benthic standing stock is essential for the assessment of demersal fishery resources, as benthos form an important source of food for demersal fishes (Damodaran, 1973; Parulekar *et al.,* 1982).

To date, there have been many benthic studies undertaken in and around Indian waters. Initially, meiobenthic studies were reported from the Cochin estuary (Kurien, 1972) and the mud bank region of Kerala (Damodaran, 1973), west coast of India. Since then, a few more qualitative and quantitative studies on sub tidal meiobenthos have been made off Indian subcontinent (Parulekar *et al.,* 1976; 1982; Ansari *et al.,* 1977; 1980; Harkantra *et al.,* 1980; Rodrigues *et al.,* 1982; Ansari and Parulekar, 1998; Ingole and Goltekar, 2004; Nanajkar and Ingole, 2007; Sajan, 2007; 2010a, b; Semprucci *et al.,* 2010, 2011, 2013, 2014; Nanajkar *et al.,* 2011; Mantha *et al.,* 2012; Ansari *et al.,* 2012 a, b; Ansari *et al.,* 2014) and a recent review on meiobenthos by Dhivya and Mohan (2013).

A perusal of literature on the meiobenthos of the Indian seas make it abundantly clear that information available on meiobenthos from the Kakinada Bay, Gaderu and Coringa estuarine complex is very scanty (Murty and Rao, 1987; Rao and Murty, 1988). The present paper gives the distribution of meiobenthos off Kakinada Bay (North and South Bay) and estuarine water ways (Coringa and Gaderu), east coast of India in relation to the prevailing environmental parameters.

The objective of the present study is aimed at describing the spatial and temporal distribution patterns of meiobenthic communities off Kakinada Bay, Gaderu and Coringa estuarine and to assess the weight of several abiotic parameters as structuring factors.

Material and methods

Study area

Kakinada Bay, a shallow bar built water body, is located on the East Coast of India (Lat. 16º 51' to 17º 00' N and Long. 82º 14' to 82º 22' E), 150 km South of Visakhapatnam (Table 1 and Fig. 1). The Bay is bound on the south by dense mangrove vegetation and extensive mudflats intercepted by a network of tidal creeks, estuarine gullies and swamps emanating from one of India's largest river systems namely, the river Godavari. Topographically, the core area is known as Coringa named after Corangi River, one of the distributaries of Gautami Godavari further south. Together with Gaderu, another distributary of Gautami Godavari, spates of fresh water are discharged into the Kakinada Bay during southwest monsoon period. Gautami Godavari joins the sea at Bhiravapalem. While the Bay is bound on the west side by the mainland, there is a sand spit (16 km long) on the east separating the Bay from the sea.

Sediment samples collected during three consecutive seasons- southwest monsoon (June and July, 1998, N=48), post-monsoon (December, 1998, N=48) and pre-monsoon (May and June, 1999, N=48) between latitudes 16º 51' to 17º 00' N and longitudes 82º 14' to 82º 22' E at 24 GPS fixed locations representing the North Bay (Sts. W7, S11, O15, W13, S17 and Y17), near the proximity of the sea; South Bay (Sts. O21, U21, Y23 and Y27), the interface between the mangroves and the North Bay; Gaderu (Sts.U27, Q31, U31, P36, Y31, U35, Q39, W37, S43, U41 and W41) and Coringa estuarine complex (Sts. Q25, O28 and K31) in the East coast of India, Bay of Bengal (Fig. 1).

Observations on the physicochemical characteristics of the sea water (dissolved oxygen and salinity) were made according to standard methods (Barnes, 1959). Sediments (sub-samples) were oven dried (60°C) onboard and stored until further analysis (Buchanan, 1984; Holme and Mc Intyre, 1984). The samples were subjected to sieving and sediment texture using a particle size analyzer- Master Sizer 2000, Melvin Instruments (Germany) and proportions of sand, silt and clay (%) were analyzed calculated and values were plotted on triangular graphs according to the nomenclature suggested by Sheppard (1954). Organic matter was estimated by the wet oxidation method of Walkey-Black but as modified by Gaudette *et al.* (1974). Biological observations included collection of quantitative meiobenthic samples.

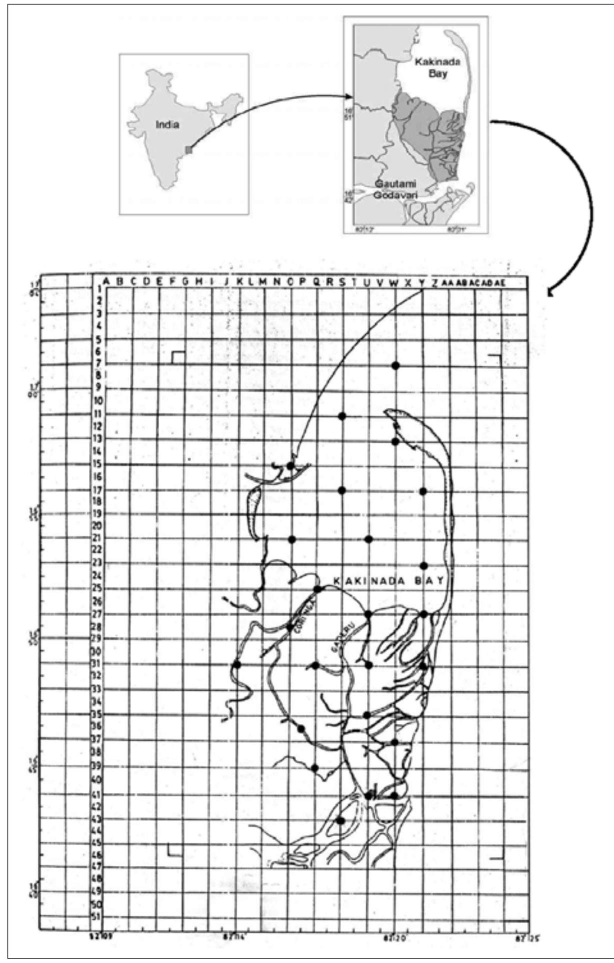

Fig. 1. Study area with station locations

Table 1. Station locations of the study area

S.No	St. No	Latitude (N)	Longitude (E)
1	W7	17°01’000”	82°20’000”
2	S11	16°59’000”	82°18’000”
3	O15	17°57’000”	82°16’000”
4	W13	16°58’000”	82°20’000”
5	S17	16°56’000”	82°18’000”
6	O21	16°54’000”	82°16’000”
7	Y17	16°56’000”	82°21’000”
8	U21	16°54’000”	82°19’000”
9	Q25	16°52’000”	82°17’000”
10	O28	16°50’500”	82°16’000”
11	K31	16°49’000”	82°14’000”
12	Y23	16°53’000”	82°21’000”
13	U27	16°51’000”	82°19’000”
14	Q31	16°49’000”	82°17’000”
15	Y27	16°51’000”	82°21’000”
16	U31	16°49’000”	82°19’000”
17	P36	16°46’500”	82°16’500”
18	Y31	16°49’000”	82°21’000”
19	U35	16°47’000”	82°19’000”
20	Q39	16°45’000”	82°17’000”
21	W37	16°46’000”	82°20’000”
22	S43	16°43’000”	82°18’000”
23	U41	16°44’000”	82°19’000”
24	W41	16°44’000”	82°20’000”

At each station, a glass corer (3.6 cm inner diameter) was used for collecting sediment samples of 10 cm length cores from grab (Hydrobios 0.1m^2, Kiel, Germany) hauls. The samples were transferred into plastic containers; living animals were narcotized with saturated $MgCl_2$ and preserved in 4% buffered formalin. The sediment samples were then processed through a set of two sieves with 500 μm and 42 μm mesh size. The residue retained on the 42 μm sieve was stored in glass container and preserved in 4% buffered formaldehyde with 2 gm of Rose Bengal as stain prior to sorting and enumeration. Meiobenthos was counted on higher taxonomic level using a binocular microscope. The total number of organisms in the sample represented by different phyla was expressed in individuals per 10 cm^2. The foraminiferan shells, only those stained by Rose Bengal were considered alive and were counted for numerical abundance. Dead shells were not considered in the numerical abundance.

Taxonomic classification of constituent species was carried out based on standard literature (Foraminifera: Ganapati and Satyavati, 1958; Vedantam and Subba Rao, 1970; Bock *et al.,* 1986; Copepoda: Lang, 1965; Ostracoda: Morkhoven, 1962-63). Nematode specimens were picked up with a fine needle and transferred into pure glycerin (Seinhorst, 1959) and mounted on Cobb slides (Cobb, 1917). Nematodes were identified using mainly the NeMys online identification key (Steyaert *et al.,* 2005, Vanaverbeke *et al.,* 2015) and other relevant literature (Platt and Warwick, 1983, 1988; Warwick *et al.,* 1998).

Table 2. Overall ranges of hydrographical parameters in different zones of study area during different seasons

	Monsoon				Post-monsoon				Pre-monsoon			
Parameter	North Bay	South Bay	Gaderu	Coringa	North Bay	South Bay	Gaderu	Coringa	North Bay	South Bay	Gaderu	Coringa
Salinity (PSU)	30.5 - 34.7	22.5 - 33.3	0 - 21.0	0.42 - 6.65	20.1 - 29.7	10.3 - 22.3	6.3 - 28.05	0.9 - 1.37	30.0 - 30.4	29.2 - 30.4	12.3 - 32.3	10.6 - 27.7
	(32.6)	(27.74)	(7.37)	(2.63)	(25.24)	(18.69)	(19.25)	(1.01)	(30.24)	(30.43)	(29.23)	(19.77)
DO (ml l^{-1})	4.5-7.1	5.5-6.8	3.6-7.4	5.0-5.6	5.7-9.6	6.0-6.3	4.4-7.3	2.4-3.0	5.5-6.8	5.1-5.6	4.5-6.7	5.05-5.9
	(5.9)	(6.22)	(6.07)	(5.36)	(6.51)	(6.13)	(5.96)	(6.58)	(5.76)	(5.47)	(5.72	(5.41)
MPD(μm)	1.4 - 23.7	5.2-38.5	1-70.3	1-9.6	1.9-71.8	3.1-3.6	1.9-26.6	2.5-8.4	1.9-135.8	1.7-26.6	2.1-114.2	3.4-57.1
	(8.07)	(13.92)	(14.16)	(4.00)	(14.5)	(3.4)	(10.17)	(4.76)	(52.15)	(8.925)	(17.61)	(33.16)
OM(%)	1.03-3.10	1.20-2.41	0.51-4.82	1.03-3.37	1.0-2.54	1.2-7.9	1.00-3.14	1.87-7.83	1-2.76	1.27-3.38	0.52-3.38	1.21-2.48
	(1.9825)	(1.595)	(2.24)	(2.218)	(1.84)	(3.96)	(1.65)	(3.9)	(1.8)	(2.49)	(2.00)	(1.75)
Sand (%)	1.24 - 60.0	17.4-77.5	0.7-68.9	0.7-31.6	1.1-82.8	9.9-22.6	4.5-72.7	4.2-35.4	2.4-90.6	11.4-50.1	2.7-84.4	42.9-67.5
	(28.07)	(40.27)	(28.29)	(11.26)	(24.8)	(17.74)	(31.38)	(16.37)	(43.41)	(22.39)	(27.1)	(53.34)
Silt (%)	4.3-74.9	2.2-32.4	11.6-31.8	20.9-28.4	5.7-28.8	20.7-25.1	6.5-32.6	18.3-33.1	0.5-31.7	11.6-30.4	3.5-36.3	4.2-20.0
	(31.64)	(18.58)	(22.3)	(23.49)	(20.8)	(23.62)	(21.08)	(25.82)	(18.05)	(23.52)	(22.96)	(12.47)
Clay(%)	1.4-69.7	20.1-50.1	11.4-75.4	47.4-77.4	11.4-73.0	54.6-65.4	20.6-71.7	46.1-69.7	5.0-70.9	24.3-76.9	11.9-71.1	12.4-52.7
	(40.56)	(41.18)	(49.86)	(65.23)	(54.39)	(58.54)	(47.53)	(57.8)	(38.53)	(54.07)	(49.92)	(34.17)

Results

Table 2 illustrates the ranges of hydrographical and sediment parameters in different zones of the study area recorded during different seasons. The salinity varied between 0.0 PSU (Gaderu, monsoon) and 34.73 PSU (North Bay, monsoon). The influence of freshwater influx is more at stations of Gaderu which are situated in the mangroves. The marine water influence is more at the stations which are situated in the North Bay of Kakinada, as it is situated on an open coast. The dissolved oxygen concentration varied between 2.4 ml l^{-1} (Coringa, post monsoon) and 9.62 ml l^{-1} (North Bay, post monsoon). The low oxygen concentration at Coringa may be attributed to the decomposing mangrove foliage and the high values at North Bay may be attributed to mixing and circulation. The MPD varied between 1.4 μm (North Bay, monsoon) and 135.8 μm (North Bay, pre-monsoon) falling between clay and silt. The organic matter content of sediment ranged from 0.51% (Gaderu, monsoon) to 7.9% (Gaderu, post-monsoon). During the study period the sediments in the North Bay, South Bay and Gaderu were sandy clay in nature where as in Coringa, it was silty clay.

A total of 122 meiobenthic species represented by Nematoda (62 sp.), Foraminifera (12 sp.), Ostracoda (18 sp.), Copepoda (10 sp.), Kinorhyncha (3 sp.), Polychaeta (13 sp.), Archiannelida (1 sp.), Tardigrada (1 sp.) and Amphipoda (2 sp.) were encountered. Overall, the order of abundance of meiobenthos has been Nematoda (37.0%), Copepoda (15.0%), Foraminifera (13.1%), Polychaeta (9.9%), Ostracoda (6.2%), Archiannelida (2.0%), Kinorhyncha (2.4%) and others (14.3%) (Fig.2). The others consisted of turbellarians, juvenile crabs, isopods, cladocerans, amphipods, cumaceans, gastropods, rotifers, hydroids, acarii, pennatulids, holothurians, priapulids, gastrotrichs and tardigrades. Among these, the priapulids (W7, North Bay, and monsoon), gastrotrichs (O15, S17, North Bay, Y17, and South Bay, post-monsoon), the pennatulids (Y17, North Bay) and tardigrada (U41, Gaderu, pre-monsoon) were encountered.

Numerically, meiobenthos abundance varied appreciably in the North Bay, South Bay, Gaderu and Coringa waterways. In particular, the meiobenthic locations in North Bay, South Bay, and Gaderu and Coringa water ways showed considerable seasonal variations, in both occurrence and abundance. The overall density at these places varied from a minimum of 14 nos.10 cm^{-2} (St. P36, Gaderu, monsoon) to a maximum of 1,038 nos.10cm^{-2} (St. Q39, Gaderu, pre-monsoon) (Table 3a, 3b,3c and Fig. 3).

Fig. 4 demonstrates the region wise (mean) density of meiobenthos for the three seasons mentioned above. It may be seen that the overall densities ranged from a minimum of 37 nos.10cm^{-2} (Coringa, post monsoon season) to a maximum of 338 nos.10cm^{-2} (South Bay, post-monsoon; North Bay, pre-monsoon season). The high mean meiobenthic densities encountered in the Bay regions may probably be due to periodic renewals (relatively clean and high saline waters) from the adjacent sea through tidal incursion. On the other hand, the low

Table 3a. Meiofaunal abundance (nos.10cm^{-2}) at different zones of study area during Pre-monsson

Groups	Pre-monsoon																							
	North Bay						South Bay					Gaderu										Coringa		
	W7	S11	W13	O15	S17	Y17	O21	U21	Y23	Y27	P36	U27	U31	Q31	U35	Y31	W37	Q39	W41	U41	S43	Q25	K31	O28
Foraminifera	165	-	16	19	-	38	-	-	12	13	-	10	15	-	11	-	12	25	-	5	10	-	-	5
Nematoda	175	200	45	46	157	199	30	105	25	205	36	25	45	35	45	9	176	258	15	64	112	25	25	6
Copepoda	55	9	7	53	3	188	31	8	49	34	28	21	104	10	5	5	135	368	15	71	16	27	11	7
Ostracoda	5	5	8	17	-	6	17	19	1	12	-	2	5	-	-	-	2	10	-	7	89	5	2	8
Polychaeta	36	14	29	32	10	173	15	11	2	17	78	2	3	10	16	3	1	9	15	7	5	4	78	9
Archiannelida	10	1	1	3	5	-	-	36	2	7	-	-	3	-	-	-	-	1	29	1	-	2	-	10
Kinorhyncha	7	-	3	2	-	-	-	8	-	5	-	-	-	-	-	-	72	48	1	-	5	-	-	11
Others	44	15	30	27	7	160	3	36	9	12	268	5	23	14	21	6	194	319	36	72	57	4	13	12
Total	497	244	139	199	182	764	96	223	100	305	410	65	198	69	98	23	592	1038	111	227	294	67	129	68

Table 3b. Meiofaunal abundance (nos.10cm-2) at different zones of study area during monsoon

Groups													Monsoon											
			North Bay					South Bay								Gaderu							Coringa	
	W7	S11	W13	O15	S17	Y17	O21	U21	Y23	Y27	P36	U27	U31	Q31	U35	Y31	W37	Q39	W41	U41	S43	Q25	K31	O28
Foraminifera	200	12	72	69	11	11	35	21	4	16	4	2	13	5	7	8	1	53	26	27	-	4	4	-
Nematoda	225	70	60	32	205	50	32	42	35	45	6	52	13	26	12	55	46	88	5	26	101	54	8	7
Copepoda	9	-	8	3	22	-	1	10	3	9	-	17	19	1	-	6	2	53	-	4	10	3	-	-
Ostracoda	5	-	25	83	27	8	30	28	1	25	3	11	7	-	6	-	-	14	8	8	-	2	-	-
Polychaeta	38	12	102	-	13	4	3	2	8	5	1	10	8	4	5	-	-	5	2	10	2	4	36	72
Archiannelida	19	-	1	-	1	-	-	-	2	2	-	1	-	-	-	1	-	-	-	-	-	1	-	1
Kinorhyncha	-	-	-	-	1	-	-	-	2	26	-	5	-	-	-	-	-	-	-	-	1	-	-	-
Others	19	3	-	2	15	-	1	-	-	4	-	2	3	-	-	3	1	1	-	-	2	2	-	-
Total	515	97	268	189	295	73	102	103	55	132	14	100	63	36	30	73	50	214	41	75	116	70	48	80

Table 3c. Meiofaunal abundance (nos.10cm-2) at different zones of study area during Post- monsoon

Groups													Post-monsoon											
			North Bay					South Bay									Gaderu							
	W7	S11	W13	O15	S17	Y17	O21	U21	Y23	Y27	P36	U27	U31	Q31	U35	Y31	W37	Q39	W41	U41	S43	Q25	K31	O28
Foraminifera	146	38	51	11	24	125	153	22	5	25	24	-	5	15	31	3	6	112	7	28	3	9	10	12
Nematoda	108	67	22	73	103	155	110	152	60	245	48	18	40	220	43	22	155	62	12	23	14	25	5	16
Copepoda	68	5	-	38	12	52	114	13	-	125	47	4	10	27	48	-	55	1	3	1	26	2	1	4
Ostracoda	37	10	43	2	13	127	41	7	5	6	13	2	2	5	-	1	3	28	2	4	7	-	-	1
Polychaeta	5	2	1	3	3	6	5	5	2	6	157	2	-	-	3	3	-	135	-	5	115	1	-	1
Archiannelida	10	-	-	-	3	32	1	78	-	-	-	-	-	-	-	-	6	-	-	10	-	-	-	-
Kinorhyncha	5	-	-	-	-	-	-	-	-	20	2	-	-	-	4	-	110	-	-	1	-	-	-	-
Others	96	10	-	42	3	49	67	57	5	29	28	10	5	7	7	7	69	5	24	6	14	3	1	7
Total	475	132	117	169	161	546	491	334	77	456	319	36	62	274	136	36	404	343	48	78	179	40	17	41

numbers in Coringa, well inside the mangroves and away from the tidal influence, could be due to the absence of any such renewal (biotic and abiotic). In general, nematodes, copepods, foraminiferans, ostracods and polychaetes were the most dominant group and contributed 81.49% of the total meiobenthic fauna (Fig. 2). The following is an account of the principal groups.

Nematoda: These were the dominant group and contributed on an average 45.61% (monsoon), 36.17% (post-monsoon) and 33.91% (pre-monsoon) of the total meiobenthic fauna (Fig. 4). Altogether, there were 62 species of nematodes. The most abundant nematode species encountered during this study include: *Sabatieria punctata, Sabatieria* sp., *Halalaimus longicaudatus, Axonolaimus* sp., *Halalaimus* sp.,

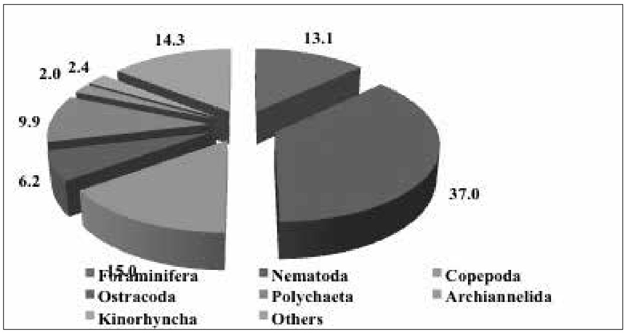

Fig. 2. Composition (%) of meiofauna in the study area

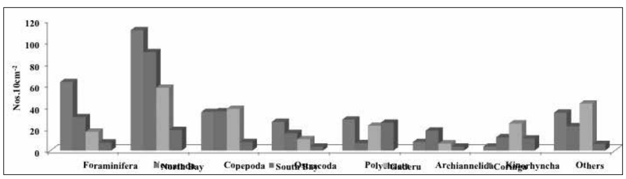

Fig. 3. Distribution of meiofaunal (mean) abundance (nos.10 cm^{-2}) in the four zones of the study area

Dorylaimopsis punctata, Metalinhomoeus longiseta, Cobbia sp., *Tricoma brevirostris, Microlaimus* sp., *Daptonema* sp., *Onyx* sp. and *Rhips* sp. Region wise, the density was least at 5 nos.10cm^{-2} (St. W41, Gaderu, monsoon and St. K31, Gaderu, post-monsoon) and maximum at 258 nos.10cm^{-2} (St. Q39, Gaderu, pre monsoon season). Changes in nematode population were presumably associated with seasonal changes in food availability. The high density of nematodes in Gaderu in pre monsoon season samples and relatively low numbers in Gaderu in monsoon (Fig. 3) could be attributed to salinity gradient and nature of sediment.

Copepoda: These are the second largest group. Copepods constituted on an average 6.34% (monsoon), 13.19% (post-monsoon) and 20.71% (pre-monsoon) of the total meiobenthic fauna (Fig. 4). Maximum densities encountered were 368 nos.10 cm^{-2} (St. Q39, Gaderu water ways, pre-monsoon season) and minimum was 1 nos.10 cm^{-2} (Sts.Q39. U41, K31, Gaderu post-monsoon and St. O21, South Bay, monsoon). Copepods increased steadily (Fig. 3). Oviparous females were fewer (9 nos.10 cm^{-2}) in December 1998 but increased steadily (98 nos.10 cm^{-2}) by pre-monsoon season (May, 1999). Copepodite stages were present in high numbers (108 nos.10 cm^{-2}) in Gaderu water ways during pre monsoon season. There were altogether, 15 species of copepods. Among these, the harpacticoids namely, *Tachidius* sp., *Stenhelia* sp., *Pseudostenhelia* sp., *Arenosetella* sp. and *Robertsonia* sp. constituted as much as 75% of the meiobenthic community.

Foraminifera: Being the third largest group, they constituted on an average 21.31% (monsoon), 17.4 % (post-monsoon season) and 5.85 % (pre-monsoon) of the total population (Fig. 4). Overall, there has been a decrease in the foraminiferan abundance although the total number of species remained constant. The minimum was 1 nos.10cm^{-2} (St. W37, Gaderu, and monsoon) and maximum encountered was 200 nos.10cm^{-2} in (St. W7, North Bay, and monsoon) with a mean 31 nos.10cm^{-2} (Fig. 3). Altogether, twelve groups were identified. Out of which five are agglutinated and seven are calcareous.

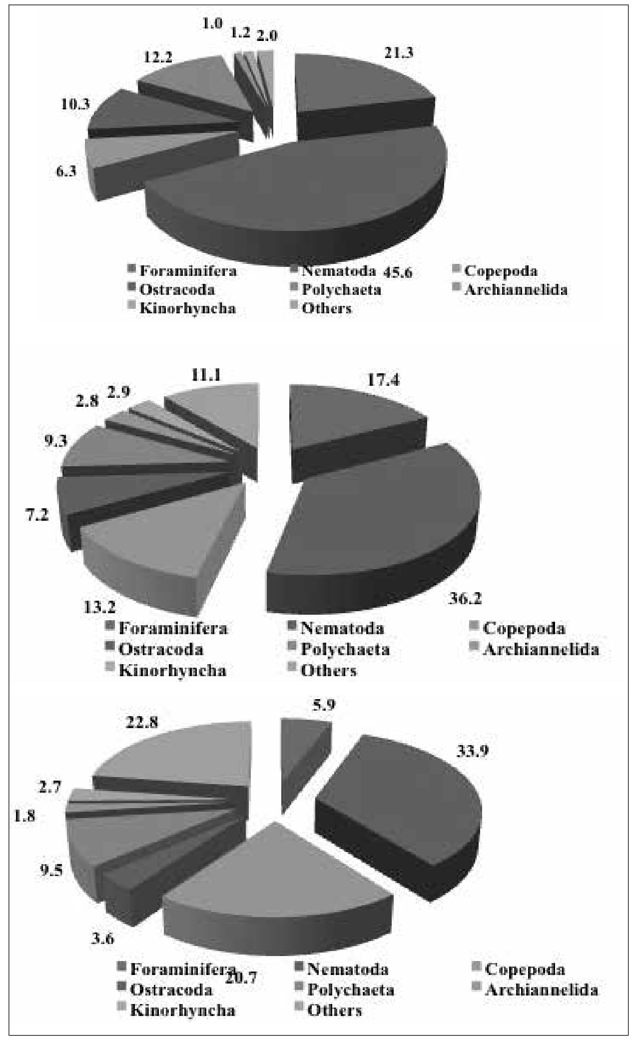

Fig. 4. Composition (%) of meiofaunal groups during various seasons in the study area

Our results suggest that agglutinated foraminiferan species *Entzia* sp. (near shore fauna) was more abundant in this study area and other foraminiferan species such as *Asterorotalia multispinosa, A. trispinosa, Ammonia* sp. and *Trochammina* sp. were most common because agglutinated assemblages prevail under conditions of greater oxygenation.

Polychaeta: These contributed on an average 12.19% (monsoon), 9.25% (post-monsoon) and 9.51% (pre-monsoon) of the total population (Fig. 4). Altogether 15 genera (including small sized forms and juveniles) were encountered. The minimum was 1 nos.10 cm^{-2} (St. W13, North Bay; Sts. Q25, O28, Gaderu, post-monsoon; St. P36, Gaderu, monsoon and St. W37, pre-monsoon) and maximum was 173 nos.10 cm^{-2} (St. Y17, North Bay, pre-monsoon) (Fig. 3). The common species were juveniles of *Prionospio* sp. and *Polydora* sp.

Ostracoda: Overall, there was a decrease in the numerical abundance of ostracods although the number of species remained more or less same. These contributed on an average 10.25% (monsoon), 7.22% (post-monsoon) and 3.61% (pre-monsoon) of the total population (Fig. 4). Minimum density encountered was 1 no.10 cm^{-2} (St. Y23, South Bay; St. Y31, post-monsoon, St. Y23, South Bay, pre-monsoon) and Gaderu maximum of 127 nos.10 cm^{-2} (St. Y17, North Bay, post-monsoon). Altogether, 18 species were encountered. The common genera were *Keijella* sp., *Neosinocyhere* sp., *Loxoconcha* sp. and *Cytherelloidea* sp.

Kinorhyncha: These contributed on an average 1.23% (monsoon), 2.85% (post-monsoon) and 2.66% (pre-monsoon) of the total population (Fig. 4). Minimum density encountered was 1 nos.10 cm^{-2} (St. S17, North Bay, monsoon, St. S43, Gaderu, monsoon; St. U41, Gaderu, pre-monsoon and St.W41, Gaderu, pre-monsoon) and maximum of 110 nos.10 cm^{-2} (St. W37, Gaderu, post-monsoon). Altogether, 3 species were encountered. Those were *Echinodereis bengalensis, Echinodereis* sp. and *Pycnophyes* sp.

Archiannelids: These contributed on an average 1.02% (monsoon), 2.81% (post-monsoon) and 1.82% (pre-monsoon) of the total population (Fig. 4). Minimum density encountered was 1 no.10 cm^{-2} (Sts. W13, S17, North Bay; Sts. U27, Y31, Gaderu and Sts.Q25, O28, monsoon; St. O21, South Bay, post-monsoon; Sts. S11, W13, North Bay, pre-monsoon) and maximum of 78 nos.10 cm^{-2} (St. U21, South Bay, post-monsoon season). A single genus *Saccocirrus* sp. was identified from the samples.

Others: These contributed on an average 2.04% (monsoon), 11.08% (post-monsoon) and 22.80% (pre-monsoon) of the total population (Fig. 4). Minimum density encountered was 1 no.10 cm^{-2} (St.K31, Gaderu, post-monsoon; St. O21, South Bay, monsoon and Sts. W37, Q39, Gaderu monsoon) and a maximum of 319 nos.10 cm^{-2} (St. Q39, Gaderu, pre-monsoon) was encountered.

Canonical Correspondence Analysis (CCA)

Using CCA routine implemented in CANOCO, meiobenthic communities were linked with environmental variables (sediment texture, MPD, organic matter and salinity). Methods such as canonical correlation and Canonical correspondence analysis (CCA) take rather a different stance of embedding the environmental data with the biotic analysis, motivated by specific gradient modes defining the species environment relationship. CCA was performed (reckon with cause-effect relationship) on selected species of nematodes (identified through BVSTEP protocols in PRIMER-Table) i.e. on the basis of their abundance and in the light of known environmental factors. Eigen values, percentage of explained variance and correlation coefficient with environmental factors, for the first four axes are given.

The four ordination axes of CCA cumulatively explained 99.9 % of the meiobenthos variance with the first two axes explaining 79.9 % of the variance (Table 4). Altogether the four axes were able to explain 47.9 to 99.9 % of variation in meiobenthic groups and environment relationships. Figure 5 shows the results of the CCA based on discriminating stations. The eigen values for the first two canonical axes were 0.076 and 0.048 respectively. In the meiobenthos data, the variance (77.9 %) accounted for the first two axes when environmental data was included. While environmental axis 1 (47.9 %) negatively correlated with salinity (r= -0.667) and positively correlated with % sand (r=0.516), Axis 2 (77.9%) showed significant

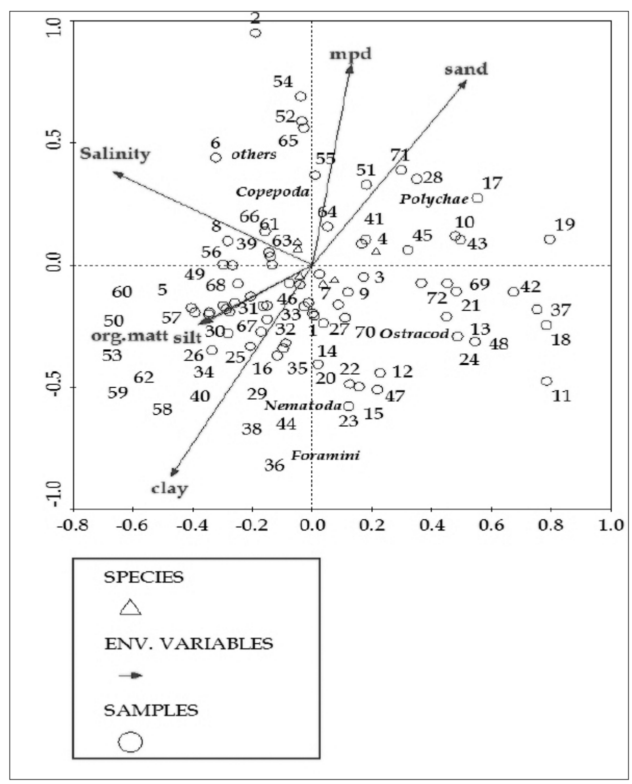

Fig. 5. Canonical correspondence analysis (CCA) showing 8 most important taxa and environmental variables. Vector lines represent the relationship of significant environmental variables to the ordination axes; their length is proportional to their relative significance. Salinity, MPD (Mean particle diameter), OM (Organic matter), Sand, Silt and Clay

positive correlation with MPD (r=0.820) and negatively with % clay (r=-0.869). Axis 3 showed negative correlations with organic matter (r=-0.306) and positively correlated with % silt (r=0.338). The triplot for meiobenthos (Fig. 5) showed that the distribution of copepods and others were influenced by salinity. In contrast, polychaetes were influenced by MPD and % sand, while organic matter, % silt and % clay influenced the distribution of nematodes and foraminiferans.

The triplot were drawn by considering the environmental variables, species and samples. Season wise, there was no differentiation between the samples and environmental variables. According to area wise, in axis-1 the stations plotted in CCA were the combination of North Bay (Sts. S11, Y17, and O15) and South Bay (St. U21), the species (copepods and others) were influenced by salinity parameter. In axis-2, the species (polychaetes) was influenced by MPD and % sand in North Bay (Sts. O51, 015 and W13) and South Bay (Sts.Y27 and O21). While in axis-3, North Bay (Sts. W7, S17, S11, and Y17) and South Bay (Sts. U21, Y23, and Y27), nematodes and foraminiferans were influenced by organic matter, % sand and clay. In axis-4, combination of Gaderu (Sts. P36, U27, U31, Q31, U35, Q39, U41 and H43) and Coringa (Sts. Q25, K31 and O28), there is no influence of environmental parameters on the biota.

Table 4. Result of CCA; Eigenvalues, species-environment correlation and percentage variance of meiofaunal taxa abundance data of Kakinada Bay, Gaderu and Coringa Estuarine complex; weighted correlation between environment variables and CCA axes. Environmental variables identified by Monte Carlo permutation tests based on forward selection with 499 unrestricted permutation; variance of environmental variables accepted at P<0.05,* Significance at P<0.05(in bold)

Axis	1	2	3	4	Total inertia
Eigenvalues	0.076	0.048	0.024	0.011	0.891
Species-environment correlations	0.505	0.439	0.396	0.341	
Cumulative percentage variance					
of species data	8.6	13.9	16.6	17.9	
of species-environment relation	47.9	77.9	92.7	99.9	
Sum of all eigenvalues					0.891
Sum of all canonical eigenvalues					0.159
Correlation coefficient					
Salinity	-0.667	0.382	-0.279	-0.430	
mpd	0.128	0.820	0.182	0.258	
org.matt	-0.369	-0.242	-0.306	0.665	
sand	0.516	0.757	-0.155	0.077	
silt	-0.382	-0.245	0.338	-0.265	
clay	-0.475	-0.869	0.034	0.036	

Discussion

Meiobenthic taxa recorded in our study were Nematoda, Copepoda, Foraminifera, Polychaeta, Ostracoda, Archiannelida, Kinorhyncha and others (turbellarians, juvenile crabs, isopods, cladocerans, amphipods, cumaceans, gastropods, rotifers, hydroids, acarii, pennatulids, holothurians, priapulids, gastrotrichs and tardigrades) (Table 3). A high number of meiobenthic taxa, some of them rare, were found in this study, demonstrating the great diversity of the meiobenthos in the Kakinada Bay, Gaderu and Coringa estuarine complex. During the present study, Nematoda was the dominant group which constituted 37% of the total meiobenthos. Similar results on the temporal variation with nematode's dominancy in meiobenthic communities have been reported from different geographical regions (Rodrıguez *et al.,* 2003; Moreno *et al.,* 2008; Semprucci *et al.,* 2010; Landers *et al.,* 2012; Harguinteguy *et al.,* 2012; Meleno *et al.,* 2013). A similar faunal composition has been reported earlier from tropical mangrove regions and other parts of India. Sarma and Wilsanand (1994) reported Nematoda, Harpacticoida, Polychaeta, Kinorhyncha, Foraminifera, Ostracoda, Oligochaeta, Bivalvia, and Tanaidacea in Bhitarkanika mangroves of the east coast of India. Likewise, Kondalarao and Ramanamurty (1988) studied similar faunal assemblages in Kakinada Bay, Gautami and the Godavari estuarine system at the east coast of India. Similar reports are also provided by Ingole *et al.* (1987) for the Saphala salt marsh of India and by Ingole and Parulekar (1998) for the Siridao Beach from the west coast of India and Mantha *et al.* (2012) from the Chennai coast, east coast of India.

In summary, the North Bay sediments with relatively high salinity (29.42 PSU, sandy clay texture) were characterized by nematodes (*Metalinhomoeus* sp., *Microlaimus* sp.) ostracods (*Cytherlloidea* sp., *Cytherella* sp.), isopods, harpacticoid copepods (*Scottlana* sp., *Phyllopodopsyllus* sp.), holothurians, hydroid and cumaceans. In contrast, the South Bay (salinity 25.58 PSU, silty clay sediments) appeared to support certain other species of nematodes (*Sabatieria* sp., *Daptonema* sp.), ostracods (*Neosinocythere* sp.), copepod (*Arenosetella* sp.), archiannelida (*Saccocirrus* sp.) and a kinorhynch (*Pycnophyes* sp.). In Gaderu water ways (salinity 18.10 PSU, sand-silt-clay), the fauna was characteristically represented by nematodes (*Enoplus* sp.), kinorhychs (*Echinodereis bengalensis, Echinodereis* sp.), copepods (S*tenhelia* sp., *Robertsonia* sp.), polychaete juveniles (*Prionospio* sp., *Polydora* sp.) and acarnids (non-halacarids). In Coringa water ways (salinity, 7.81 PSU, sandy clay), the fauna showed different elements represented by nematodes (*Viscosia* sp.), ostracods (*Cypridopsis angularis, Copytus* sp.) and juveniles of polychaetes (*Prionospio* sp.).

The observations also revealed that the spatial and temporal variations among the meiobenthos in Coringa complex are principally governed by the seasonal monsoons. In general, the high numerical abundance coincided with high and stable salinity during pre- monsoon season (May 1999) and low abundance with low and fluctuating salinity noticed in south west monsoon. The meiobenthic forms are known to feed actively on diatoms, bacteria, protozoans, detritus, and dissolved organic carbon. Therefore, availability of food seemed an important limiting factor in controlling their abundance.

The sub tidal meiobenthos of the Kakinada Bay and estuarine water ways showed considerable fluctuations, in occurrence, abundance and standing stock biomass. The faunal density which was lowest in phase I (June - July, monsoon season), increased progressively and reached peak in the hot weather season (May - June, pre-monsoon). Similar trends in the abundance of meiobenthos have been reported earlier from the Indian coast (Damodaran, 1973, Rao and Murty, 1988 and Ansari and Parulekar, 1993). The seasonality was greatly influenced by the monsoonal rain. The erosion and re suspension of the sediment surface and lowering the salinity during monsoon causes mortality. Such detrimental effect of monsoon on meiobenthos has been reported by earlier workers (Ansari *et al.,* 1984; Reddy and Hari Haran, 1985; Kondala Rao and Murty, 1988; Ansari and Parulekar, 1993) from both east and west coast of India. Seasonality in the meiobenthic abundance is attributable to excess food sources particularly the microphytobenthos and increase in salinity during pre-monsoon period. In conclusion, the high abundance of harpacticoid copepods, particularly copepodites, nauplii and ovigerous females showed that these meiobenthic copepods are reproductively active during premonsoon season, and are well suited to this climatic regime with their tolerant and adaptive natures. Furthermore, long-term mesocosm experimental studies could provide more information on the nature and stability of these meiofauna assemblages with high reproductive and developmental strategies (Mantha *et al.,* 2012).

The CCA analyses showed that salinity along with sediment texture influenced the meiobenthic abundance in the Kakinada Bay, Gaderu and Coringa estuarine complex. It is recommended to include meiobenthic community level analysis in future environmental studies for a better understanding of coastal marine ecosystems.

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