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Seasonal Distribution of Zooplankton in Mahanadi Estuary (Odisha), East Coast of India: A Taxonomical Approach

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ABSTRACT

Study of coastal and estuarine water is important as they act as a medium of exchange of materials between land and ocean. Mahanadi estuarine system forms the largest system of its kind in Odisha. Zooplankton, the secondary producers plays a vital role in the hydrobiology and food chain regulation. The zooplankton diversity of Mahanadi estuary (Odisha) was investigated during postmonsoon (December 2009), premonsoon (April 2010) and monsoon (July 2010). Important hydrographical parameters such as water temperature, salinity, pH and dissolved oxygen, NO_2 (nitrite), NO_3 (nitrate), NH_4 (ammonia), TN (total nitrogen), PO_4 (phosphate), TP (total phosphorous) and SiO_4 (silicate) were measured during the present study along with the study of the qualitative and quantitative aspects of zooplankton. Zooplankton population dominated by copepod at all the stations in all the seasons except during low tide of premonsoon season where caridean larvae were dominant. In total, 86 species of zooplankton, mostly belonging to Crustacea, Chaetognatha, Mollusca, Polychaeta, Cnidaria, Ctenophora, Protozoa, Larvacea among the holoplankton and 16 different types of larval forms were encountered. The population density ranged from 52 to 885 org. m^{-3} with highest density during high tide of post-monsoon i.e., 885 org. m^{-3}. The copepods like *Subeucalanus mucronatus, Subeucalanus subcrassus, Sapphirina maculosa, Sapphirina auronitens* are recorded for the first time from marine and estuarine ecosystem of Odisha. Presence of 16 different crustacean dominated larval forms signifies the conduciveness of estuary during the whole period for breeding and spawning of shell fishes in the estuary. During the present study, zooplankton population density was positively related with zooplankton biomass.

Key words: Zooplankton, Mahanadi estuary, copepod, salinity

INTRODUCTION

Estuaries act as a transitional zone between land and sea (Ketchum, 1951) and they serve as abodes for a great variety of flora and fauna having tremendous socioeconomic and ecological significance. Zooplankton by their major abundance and diversity forms the most important community in the estuarine zone. Zooplankton regulates the pelagic food chain by controlling primary production. Many zooplankton species are used as good indicator of coastal water pollution. A few zooplankton such as copepods are also used in pharmaceutical industries. From the fishery point of view, zooplankton production is used as an index of potential harvest. Considering their multiple utility extensive studies have been made dealing with the taxonomy, ecology and biochemical composition of marine and estuarine zooplankton all over the globe (Raymont, 1983). Available literature however suggests that zooplankton studies from tropical areas are less compared to those in high latitudes. The literature reviews (Grindley, 1981; Miller, 1983; Madhupratap, 1987) also showed that estuarine zooplankton studies from tropical and subtropical region are less compared to those of temperate region. Further they opined that more research, particularly, the ecological aspects of estuarine zooplankton in tropical and subtropical areas need to be made extensively.

The review of Madhupratap (1987) and other publications on estuarine zooplankton of India shows that, the investigations over the years were mostly limited to the Cochin backwater (George 1958; Haridas *et al.*, 1973; Menon *et al.*, 1971; Wellershaus, 1974; Madhupratap and Haridas, 1975; Silas and Pillai, 1975; Madhupratap, 1978, 1979, 1980), Vellar estuary (Seshadri, 1957; Krishnamurthy, 1967; Subbaraju and Krishnamurthy, 1972; Santhanam *et al.*, 1975; Chandran and Ramamurthi, 1984; Shanmugam *et al.*, 1986), Zuari and Mandovi estuaries (Goswami and Singbal, 1974; Goswami and Selvakumar, 1977; Goswami, 1982, 1983; Padmavati and Goswami, 1996), Hooghly estuary (Dutta *et al.*, 1954; Roy, 1955; Shetty *et al.*, 1961; Saha *et al.*, 1975; Sarkar *et al.*, 1984, 1986; Sarkar and Singh, 1986) and Kaduviyar estuary (Perumal *et al.*, 2009).

As far as the Odisha coast is concerned, zooplankton studies mostly limited to a few estuaries (Gouda and Panigrahy, 1995; Mishra and Panigrahy, 1999; Ramaiah *et al.*, 1996), Chilka Lake (Patnaik, 1973; Sewell, 1914; Naik *et al.*, 2008) and coastal waters of Bay of Bengal, off Rushikulya estuary (Sahu *et al.*, 2010). Presently, there is no published work on the zooplankton of Mahanadi estuary. So, the study was carried out to investigate the zooplankton community of Mahanadi estuary and provide a systematic list that will therefore be useful in improving knowledge of the estuarine zooplankton in the region of Odisha.

MATERIALS AND METHODS

Study site: Mahanadi river system is the third largest in the peninsula of India and the largest river in Odisha state. It has its origin near Sihawa in the Raipur district, Madhya Pradesh and after travelling a distance of nearly 857 km debouches into the Bay of Bengal near Paradip, Odisha. There is heavy industrial activity in Paradip and upstream of Mahanadi estuary. It also receives a large amount of agricultural run-off along its course. Human influences are pronounced at Sambalpur, Cuttack and Paradip where the proliferation of industries and sewage discharges are prominent. The nutrient rich water after travelling all the distances enters Bay of Bengal through the Mahanadi river mouth at Paradip. The drainage basin area of the Mahanadi is 1.42×10^5 km^2 yielding a total annual runoff of 50×10^9 m^3. The tidal, estuarine part of the river covers a length of 40 km and a basin area of 9 km^2. On the basis of physical characteristics, it is classified as partially-mixed coastal plain estuary. Seasonal variations of rainfall have strong effects on the river discharge and subsequently on the concentration of pollutants in river water.

Collection of water and zooplankton samples: Water and zooplankton samples were collected from Mahanadi estuary (lat. 20° 17'37"N and long. 86° 42'25"E) during 2009-2010 (Fig. 1). The surface sampling was carried out at an interval of 3 hour in three different seasons such as, postmonsoon (December), premonsoon (April) and monsoon (July). pH, air and water temperature were measured using a Seawater Analysis Kit (Make WTW). Salinity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) and analysis of different nutrients like Nitrate (NO_3), Nitrite

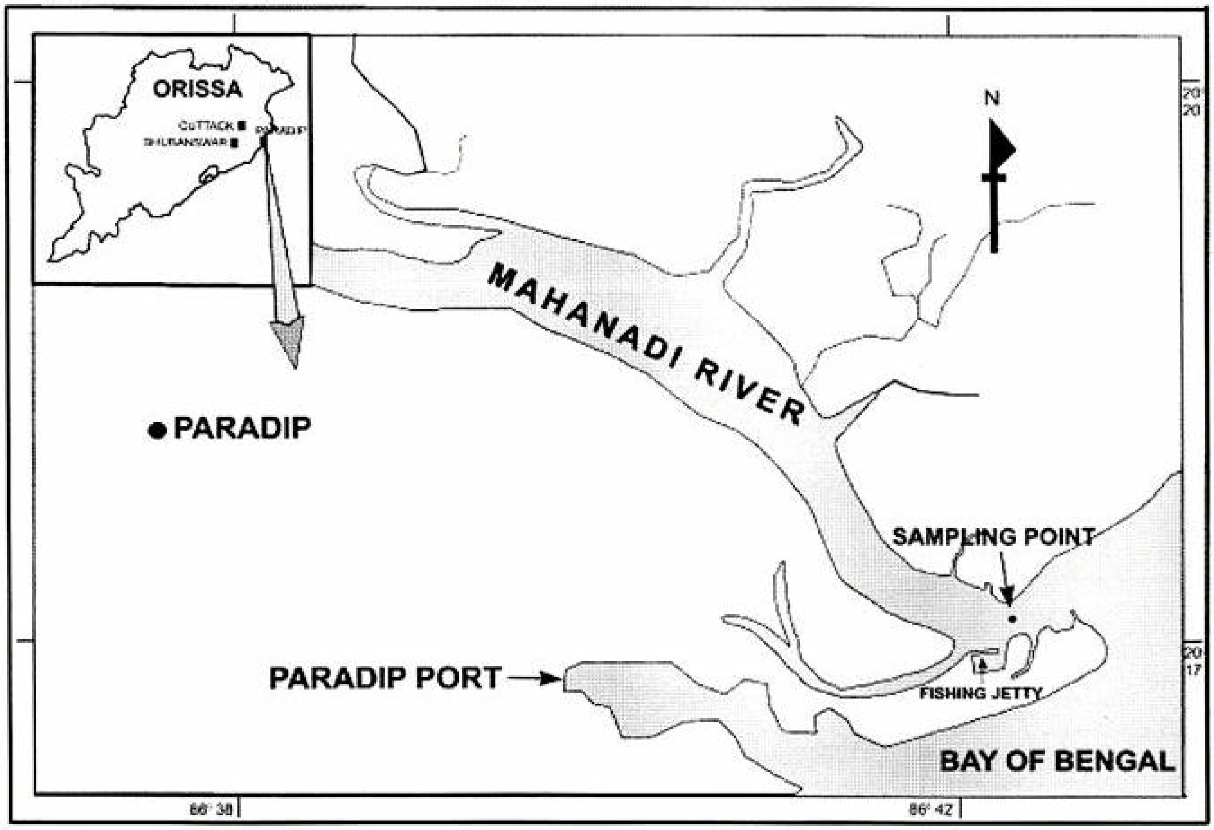

Fig. 1: Showing sampling location of Mahanadi Estuary, Box: Zooplankton Population; Line: Zooplankton Biomass, HT: High Tide; MT: Mid Tide; LT: Low Tide

(NO_2), Ammonia (NH_4), Phosphate (PO_4), Silicate (SiO_4), Total Nitrogen (TN) and Total Phosphorous (TP) were determined by standard procedures prescribed by APHA (1998).

Zooplankton samples were collected by horizontal haul using a conical plankton net, (mesh size of 300 µm) and preserved with 5% neutralized formaldehyde after their collection. In the laboratory, the zooplankton samples were divided into two subsamples with the help of a Folsom Plankton Splitter for quantitative and qualitative analysis. From one subsample, the biomass was determined following the volume displacement method. Estimation of qualitative composition of the zooplankton was done with other subsample. The numerical abundance values were represented in org. m^{-3}. The relative abundance was computed from total density and the density of each group. Standard literatures and some invertebrate texts were referred for identification of organisms (Kasturirangan, 1963; Newell and Newell, 1977; Conway *et al*., 2003).

RESULTS

Hydrographical parameters: Hydrographical parameters in an estuarine and lagoon ecosystem are controlled by the combined influence of the ongoing physical, chemical and biological processes. All the 14 hydrological parameters such as depth, air temperature, water temperature, salinity, pH, dissolved oxygen, biological oxygen demand, NO_2, NO_3, NH_4, TN, PO_4, TP, SiO_4 showed visible tidal and seasonal variations during the present study (Table 1). The mean values of hydrographical parameters are given in Table 1 for postmonsoon, premonsoon and monsoon. Avg. depth of water column varied from 12.8 m (monsoon) to 13.4 m (postmonsoon) during the study period. The mean air temperatures were 24.7, 29.5 and 30.7°C in postmonsoon, premonsoon and monsoon, respectively.

Water temperature during the study ranged from 25.30-31.0°C. The salinity values during the present study ranged from 7.33PSU-19.32 PSU while pH values were between 7.74 and 8.14. A seasonal salinity trend: postmonsoon >premonsoon>monsoon was noticed. This lower value of salinity during monsoon were comparable with the earlier observations made by Vareethiah (1999) and Achary *et al.* (2010). The mean dissolved oxygen contents were 7.65, 7.59, 7.84 mg L^{-1} during postmonsoon, premonsoon and monsoon respectively showing homogeneous situation over the year. Average NO_2 was found higher in monsoon period (0.33 µmol L^{-1}) but lower in post-monsoon season (0.16 µmol L^{-1}). A seasonal nitrite trend: monsoon >premonsoon >postmonsoon was noticed. Average NO_3 concentration was found maximum in pre-monsoon (9.98 µmol L^{-1}) and minimum in post-monsoon (2.54 µmol L^{-1}). The NH_4 concentration was maximum in monsoon (3.25 µmol L^{-1}) and minimum in postmonsoon (1.16 µmol L^{-1}). PO_4 (5.39 µmol L^{-1}) and TP (6.06 µmol L^{-1}) was found higher in postmonsoon where as lowest in pre-monsoon. SiO_4 value was found high in monsoon (66.26 µmol L^{-1}) and lowest in postmonsoon (16.23 µmol L^{-1}). Mean Chl-*a* showed its maximum in monsoon (4.83 mg m^{-3}) and minimum in premonsoon (0.63 mg m^{-3}).

Tidal variation showed that during postmonsoon highest air temperature (26.0°C), BOD (2.01 mg L^{-1}), NO_2 (0.21 µmol L^{-1}), NO_3 (3.36 µmol L^{-1}), NH_4 (1.39 µmol L^{-1}), TN (32.91 µmol L^{-1}), PO_4 (8.71 µmol L^{-1}), TP (9.21 µmol L^{-1}), SiO_4 (18.91 µmol L^{-1}) were observed during low tide, highest water temperature (25.60°C) and salinity (22.52 PSU) during mid tide and highest pH (8.17) and DO (8.06 mg L^{-1}) during high tide (Table 1).

During pre-monsoon, higher values of salinity (23.47 PSU), pH (8.28), DO (7.74 mg L^{-1}) were observed during high tide. But during mid tide, water temperature (30.40°C), NO_2 (0.30 µmol L^{-1}), NO_3 (13.24 µmol L^{-1}), NH_4 (1.34 µmol L^{-1}), TN (46.92 µmol L^{-1}), PO_4 (3.31 µmol L^{-1}), TP

Table 1: Hydrographical and Biological parameters in Mahanadi estuary during postmonsoon, premonsoon and monsoon (2009-2010)

	Post-monsoon				Pre-monsoon				Monsoon			
Parameters	LT	MT	HT	Avg.	LT	MT	HT	Avg.	LT	MT	HT	Avg.
Air Temp. (°C)	26.00	24.70	23.40	24.70	27.80	30.40	30.40	29.53	29.30	31.50	31.20	30.67
Water Temp. (°C)	24.80	25.60	25.40	25.27	28.40	30.40	29.60	29.47	30.60	31.10	31.40	31.03
Depth (m)	12.30	13.20	14.80	13.43	12.20	13.40	14.10	13.23	12.20	12.80	13.30	12.77
Salinity (PSU)	13.14	22.52	22.30	19.32	8.95	14.91	23.47	15.78	5.22	7.14	9.62	7.33
pH	7.90	7.16	8.17	7.74	7.96	8.18	8.28	8.14	7.99	8.08	8.19	8.09
DO (mg L^{-1})	7.16	7.74	8.06	7.65	7.42	7.61	7.74	7.59	7.74	7.81	7.97	7.84
BOD (mg L^{-1})	2.01	1.30	0.97	1.43	0.91	0.84	0.78	0.84	2.20	2.14	2.17	2.17
NO_2 (µmol L^{-1})	0.21	0.17	0.11	0.16	0.28	0.30	0.23	0.27	0.49	0.22	0.29	0.33
NO_3 (µmol L^{-1})	3.36	2.37	1.89	2.54	10.46	13.24	6.23	9.98	4.12	3.35	2.98	3.48
NH_4(µmol L^{-1})	1.39	1.07	1.03	1.16	1.28	1.34	1.13	1.25	3.84	2.41	3.51	3.25
TN(µmol L^{-1})	32.91	28.52	23.12	28.18	44.22	46.92	40.84	43.99	46.22	34.26	32.38	37.62
PO_4(µmol L^{-1})	8.71	4.20	3.25	5.39	1.69	3.31	1.88	2.29	5.74	2.95	2.08	3.59
TP(µmol L^{-1})	9.21	4.96	4.02	6.06	2.23	4.26	2.70	3.06	6.89	4.02	3.86	4.92
SiO_4 (µmol L^{-1})	18.91	15.64	14.15	16.23	63.10	37.91	25.43	42.15	97.37	50.06	51.36	66.26
Chl-a (mg m^{-3})	2.21	1.27	1.20	1.56	0.43	0.72	0.74	0.63	4.15	5.23	5.09	4.83
ZooBio (mL m^{-3})	0.50	3.00	1.00	1.50	0.16	0.16	0.64	0.32	0.08	1.28	0.40	0.59
ZooPop (org m^{-3})	422	287	885	532	141	750	196	137	52	456	184	231

(4.26 µmol L^{-1}) were higher as compared to the high tide and low tide. The values of BOD (0.91 mg L^{-1}) and SiO_4 (63.10 µmol L^{-1}) were higher during low tide (Table 1).

Like postmonsoon, the high values of BOD (2.02 mg L^{-1}), NO_2 (0.49 µmol L^{-1}), NO_3 (4.12 µmol L^{-1}), NH_4, (3.84 µmol L^{-1}), TN (46.22 µmol L^{-1}), PO_4 (5.74 µmol L^{-1}), TP (6.89 µmol L^{-1}), SiO_4 (97.37 µmol L^{-1}) were recorded during low tide of monsoon season. Maximum value of DO (7.97 mg L^{-1}), pH (8.19), water temperature (31.40°C) and salinity (9.62 PSU) were recorded during high tide where as air temperature (31.50°C) were higher during mid tide (Table 1).

Zooplankton

Species composition: The zooplankton community of Mahanadi estuary during the present study was represented by 86 species of holoplankters belonging to 19 diverse groups (Table 2, 3) and 16 different types of meroplankters (Table 2). The holoplankton community mainly comprised of protozoans, hydrozoa, siphonophores, ctenophores, a variety of crustaceans (like copepods, cladocerans, ostracods, euphausiids, decapods, isopods, mysids, amphipods), gastropods, chaetognaths and tunicates like *Oikopleura* and *Fritillaria*. Details of the species composition is summarized here below.

Protozoa: The protozoan population were represented by four different species of tintinnids namely *Tintinnopsis butschlii, T. cylindrica, T. nordqvisti, T. beroidea* and three different species of foraminifers i.e., *Globigerina* sp. and two unidentified benthic foraminifera. Among these six species, *Tintinniopsis butschlii* and *Globigerina* sp. were more abundant than others. Tintinnids were observed only during high tide of pre-monsoon and monsoon with very low numerical abundance whereas completely absent during postmonsoon. Foraminifera were noticed only during the premonsoon of all the 3 tides.

Copepod: Among all the groups, copepod formed dominant component of the zooplankton (31.39 to 95.31%) in all the samples collected during three seasons over the tidal cycle except during low tide of monsoon where caridean larvae (34.73%) remained dominant form (Table 2). The population density of copepod showed well marked seasonal and tidal variation (Table 2). The average population density of copepod was higher during post-monsoon (487 org. m^{-3}) followed by monsoon (175 org. m^{-3}) and pre-monsoon (120 org. m^{-3}). Higher value of copepod during post-monsoon was also previously reported at Muttukadu Back water, Chennai (Bharathi Devi and Ramanibai, 2012). Many workers have reported the contribution of copepods up to 96.4% (Sarkar *et al*., 1986), 97.0% (Sarkar and Singh, 1986), 91.25% (Gouda and Panigrahy, 1995), 94.99% (Naik *et al*., 2008), 95.2% (Bhunia and Choudhury, 1982), 94.2% (Shanmugam *et al*., 1986). These relative abundances of copepod can be comparable with the present study i.e., up to 95.31%.

Other crustacean: The other crustacean taxa encountered during the present study included the Cladocerans, Ostracods, Mysids, Euphausiids, Cumaceans, Decapods, Isopods and Amphipods. Four species of cladocerans namely *Evadne tergestina, Penilia avirostris, Diaphanosoma leuchternbergianum, Sida* sp. were encountered during this study. Of these four, *Penilia avirostris* was more abundant in pre-monsoon collection while *Sida* sp. in monsoon season. Occurrence of limnetic cladocerans during the monsoon season was also reported by Goswami *et al.* (1979). During the present study, maximum and minimum numbers of cladocerans were observed during the monsoon and postmonsoon respectively (Table 2). These results are in agree with the other

Table 2: Seasonal and tidal distribution of different zooplankton groups in Mahanadi estuary

	Post-monsoon			Pre-monsoon			Monsoon		
Group	LT	MT	HT	LT	MT	HT	LT	MT	HT
Amphipod	-	0.3(0.10)	-	-	-	-	-	-	-
Appendicularians	3 (0.70)	5 (1.70)	17 (1.88)	1 (0.37)	0.1 (0.13)	2 (1.20)	0.3 (0.56)	-	-
Chaetognaths	-	-	-	-	-	1 (0.37)	-	-	-
Cladocerans	6 (1.29)	2 (0.82)	-	-	-	0.2 (0.09)	15 (28.34)	14 (3.04)	1 (0.41)
Copepods	370 (86.45)	247 (86.07)	844 (95.31)	128 (90.81)	65 (87.27)	168 (85.73)	16 (31.39)	405(88.73)	105 (57.07)
Ctenophores	-	0.1 (0.05)	-	-	-	-	-	-	-
Euphansiids	-	-	-	-	-	3 (1.58)	-	-	-
Foraminifera	-	-	-	2 (1.69)	0.1 (0.13)	0.2 (0.09)	-	-	-
Gastropoda	1 (0.12)	4 (1.28)	6(0.70)	0.2 (0.15)	-	0.2 (0.09)	-	-	0.1 (0.03)
Hydroidomednsae	-	1.2 (0.4)	2 (0.23)	-	-	-	-	0.3 (0.06)	-
Isopod	5 (1.17)	9 (3.24)	-	-	-	1 (0.65)	-	-	-
Lamellibranch	-	-	-	1 (0.44)	-		-	-	-
Lucifer	1 (0.12)	0.1 (0.05)	**	-	1 (0.79)	1 (0.46)	0.4 (0.83)	1 (0.18)	15 (7.90)
Mysids	2(0.47)	-	-	-	-	-	-	-	-
Ostracods	-	-	-	-	-	1 (0.46)	-	-	-
Penaeid Prawn	-	-	-	3 (1.84)	3 (3.54)	0.4 (0.19)	-	-	-
Polychaete	3(0.70)	0.3 (0.10)	-	0.1 (0.07)	-	0.2 (0.09)	-	2 (0.42)	0.2 (0.10)
Siphonophores	-	3 (1.08)	8(0.94)	-	-	1 (0.28)	-	-	-
Tintinnids	-	-	-	-	-	0.2 (0.09)	-	-	0.2 (0.10)
Alima larva of Squilla	1 (0.12)	0.1 (0.05)	-	-	-	-	-	-	-
Bivalve veliger	2 (0.35)	0.1 (0.05)	-	0.3 (0.22)	0.2 (0.26)	0.4 (0.19)	0.1(0.28)	3 (0.60)	0.3 (0.17)
Brachiopod Larvae	13 (3.04)	5 (1.80)	4(0.47)	-	-	-	-	-	-
Caridean Larvae	9 (2.10)	4 (1.39)	-	2 (1.10)	1 (1.44)	0.2 (0.09)	18 (34.73)	19 (4.24)	35 (19.03)
Cirripede cypris	2 (0.47)	-	-	-	-	0.4 (0.19)		0.3 (0.06)	0.2 (0.10)
Cirripede nauplius	-	-	-	-	-	-	0.1 (0.28)	0.3 (0.06)	1 (0.54)
Copepod nauplii	-	-	-	3 (1.84)	1 (1.44)	3 (1.48)	-	-	7 (3.71)
Echinoderm larvae	-	1 (0.26)	-			2 (0.83)	-	-	-
Fish egg	1 (0.23)	1 (0.26)	-	1 (0.51)	1 (1.05)	10 (5.28)	-	-	-
Fish Larvae	1 (0.12)	-	-	0.1 (0.07)	0.2 (0.26)	-	-	-	1 (0.34)
Gastropod veliger	-	2(0.77)	-	0.1 (0.07)	0.5 (0.66)	0.4 (0.19)	1 (1.11)	4 (0.95)	5 (2.49)
Megalopa Larva of Brachyuran	-	-	-	0.1 (0.07)	-	-	0.1 (0.28)	-	-
Polychaete Larvae	-	-	-	-	-	-	0.1 (0.28)	2 (0.42)	0.4 (0.20)
Phoronida larva	-	-	-	-	-	-	1 (1.11)	5 (1.19)	13 (7.22)
Zoeal Larva of Brachyurans	11 (2.45)	1 (0.51)	4 (0.47)	1 (0.73)	2 (3.02)	1 (0.37)	0.4 (0.83)	0.3 (0.06)	1 (0.58)
Megalopa Larva of Pagurid crab	1 (0.12)	-	-	-	-	-	-	-	-

observation of Goswami *et al.* (1979). Two species of ostracods namely *Conchoecia elegans* and *Conchoecia* sp. were found during present study. Mysids were represented by only 2 species i.e., *Mesopodopsis orientalis* and *Neomysis* sp. The other crustacean which made sporadic appearance included amphipoda (*Leucothoe spinicarpa*), Euphausiaceae (*Euphausia* sp.), Decapoda (*Lucifer hanseni*) and Isopoda (*Edotea triloba*).

Other non-crustacean zooplankton

Siphonophores and Hydroidomedusae: Siphonophora population of Mahanadi estuary comprised of three species, belonging to family Diphyidae during the study period. They were

Table 3: Checklist of Holoplankton encountered in Mahanadi estuary

Phylum	Class	Subclass	Order	Family	Name of species
Holoplankton					
Protozoa	Ciliata		Tintinnida	Tintinnidae	*Tintinnopsis butschlii* Daday (1887)
					Tintinnopsis cylindrica Daday (1887)
					Tintinnopsis nordqvisti Brandt (1906)
					Tintinnopsis beroidea Stein (1867)
	Granuloreticulosea		Foraminiferida	Globigerinidae	*Globigerina* sp.
					unidentified benthic foraminifera
Cnidaria	Hydrozoa	Hydroidomedusae	Leptomedusae	Campanulariidae	*Obelia* sp.
				Phialellidae	*Phialella quadrata* Forbes (1848)
			Semaeostomeae	Ulmaridae	*Aurelia aurita* Linnaeus (1758)
		Siphonophorae	Calycophorae	Diphyidae	*Diphyes dispar* Chamisso and Eysenhardt (1821)
					Sulculeolaria sp.
					Lensia sp.
Ctenophora	Tentaculata		Cydippida	Pleurobrachiidae	*Pleurobrachia globosa* Moser (1903)
Annelida	Polychaeta		Phyllodocida	Tomopteridae	*Tomopteris* sp.
Arthropoda	Crustacea	Branchiopoda	Cladocera	Polyphemidae	*Evadne tergestina* Claus (1877)
					Penilia avirostris Dana (1852)
				Sididae	*Diaphanosoma leuchternbergianum* Fischer (1854)
					Sida sp.
		Ostracoda	Myodocopida	Cypridinidae	*Conchoecia elegans* Sars (1866)
					Conchoecia sp.
		Copepoda	Calanoida	Calanidae	*Canthocalanus pauper* Giesbrecht (1888)
					Nannocalanus minor Claus (1863)
				Encalanidae	*Eucalanus monachus* Giesbrecht (1888)
					Subeucalanus subcrassus Giesbrecht (1888)
					S. mucronatus Giesbrecht (1888)
					Eucalanus sp.
				Paracalanidae	*Acrocalanus gracilis* Giesbrecht (1888)
					A. longicornis Giesbrecht (1888)
					A. gibber Giesbrecht (1888)
					Paracalanus aculeatus Giesbrecht (1888)
					P. parvus Claus (1863)
				Centropegidae	*Centropages orsinii* Giesbrecht (1889)
					C. furcatus Dana (1849)
				Pseudodiap tomidae	*Pseudodiaptomus aurivilli* Cleve (1901)
					P. serricaudatus T.Scott (1894)
				Temoridae	*Temora discaudata* Giesbrecht (1889)
					T. turbinata Dana (1849)
				Arietellidae	*Metacalanus aurivilli* Cleve (1901)
				Candaciidae	*Candacia* sp.
				Pontellidae	*Labidocera acuta* Dana (1849)
					L.pectinata Thompson and Scott (1903)
					Pontella danae Giesbrecht,
					P.securifer Brady (1883)
					P.spinipes Giesbrecht (1889)
					Calanopia minor A. Scott (1902)
				Acartiidae	*Acartia chilkaensis* Sewell (1919)
					A. erythraea Giesbrecht (1889)

Table 3: Continue

Phylum	Class	Subclass	Order	Family	Name of Species
					A. centrura Giesbrecht (1889)
					A. spinicauda Giesbrecht (1889)
					A. danae Giesbrecht (1889)
					A. negligens Dana (1849)
					Acartia sp.
				Tortanidae	*Tortanus forcipatus* Giesbrecht (1889)
			Cyclopoida	Corycaeidae	*Corycaeus agilis* Dana (1849)
					C. andrewsi Farran (1911)
					C. catus F. Dahl (1894)
					C. danae Giesbrecht (1891)
					Corycaeus sp.
					Cyclops sp.
				Oithonidae	*Oithona rigida* Giesbrecht (1896)
					O. brevicornis Giesbrecht (1891)
					O. spinirostris Claus (1863)
					Oithona sp.
				Oncaeidae	*Oncaea venusta* Philippi (1843)
			Poecilostomatoida	Sapphirinidae	*Sapphirina maculosa* Giesbrecht (1892)
					S. auronitens Claus (1863)
			Harpacticoida	Ectinosomidae	*Microsetella norvegica* Boeck (1864)
					M. rosea Dana (1848)
				Clytemnestridae	*Clytemnestra scutellata* Dana (1848)
				Tachidiidae	*Euterpina acutifrons* Dana (1848)
			Siphonostomatoida	Caligidae	*Alebion* sp.
		Malacostraca	Amphipoda	Lencothoidae	*Leucothoe spinicarpa* Abildgaard (1789)
			Mysidacea	Mysidae	*Mesopodopsis orientalis* W. Tattersall (1908)
					Neomysis sp.
			Euphausiacea	Euphausiidae	*Euphausia* sp.
			Decapoda	Sergestoidae	*Lucifer hanseni* Nobili (1905)
				Penaeoidea	Penaeus sp.
			Isopoda		*Edotea triloba* Say (1818)
Mollusca	Gastropoda	Euthyneura	Thecosomata	Limacinidae	*Limacina inflata* D' Orbigny (1836)
				Cavoliniidae	*Cresis acicula* Rang (1828)
Chaetognatha	Sagittoidae		Aphragmophora	Sagittidae	*Sagitta enflata* Grassi (1881)
					S. bedoti Beraneck (1895)
					S. robusta Doncaster (1902)
Chordata	Larvacea		Appendicularia	Fritillariidae	*Fritillaria* sp.
					Oikopleura parva Lohmann (1896)
					Oikopleura dioica Fol (1872)

Diphyes dispar, *Lensia* sp. and *Sulculeolaria* sp. (Table 3). They however, made sporadic appearance. In addition to these three species of Siphonophores, *Obelia* sp., *Phialella quadrata* and *Aurelia aurita* of Hydroidomedusae were also encountered.

Ctenophores: The planktonic ctenophore of Mahanadi estuary was represented by only one specie i.e., *Pleurobrachia globosa* belonging to family Pleurobrachiidae which made sporadic appearance during the study period with a very low relative abundance of 0.05% (Table 2). The occurrence of these species was very negligible as compared to other zooplankters and the same was also reported by Sahu *et al.* (2010).

Polychaetes: This group was represented by only one species of *Tomopteris* sp.

Molluscs: The planktonic molluscs of the Mahanadi estuary were represented by two species-*Limacina inflata* and *Cresis acicula*. They were seen commonly in most of the collections.

Chaetognatha: Three species namely *Sagitta bedoti, S. enflata, S. robusta* were encountered during the present study. However, these species were found only during the high tide of premonsoon.

Larvacea: This group was represented by three species i.e., *Oikopleura parva, Oikopleura dioica* and *Fritillaria* sp. *Oikopleura dioica*, however, is more abundant than other two species (Table 3). The relative abundance of appendicularians were higher during high tide of postmonsoon and premonsoon where as during monsoon they were completely absent during high tide and mid tide and appeared with a very low %composition during low tide (Table 2).

Meroplankton: The meroplankton component of the present study was represented mainly by 7 larval groups. They were the larvae of Crustacean, Molluscs, Polychaetes, Brachiopods, Echinoderms, Phoronida, fish egg and fish larvae. The crustacean larval population mostly comprised of nauplius, zoea, megalopa, alima and these all together contributed 0.47-36.12%. Among the crustacean larvae, the zoea larvae of Brachyurans were found in entire collections over the year (Table 2). Caridean larva contributed 0.09-34.73% of the total zooplankton density and even occupied the first order of dominancy during low tide of Monsoon (Table 2). Molluscan veligers were also encountered at almost all stations during the entire period of observation. Larvae of Polychaetes were less in number compared to others. The Lingula larvas of Brachiopods were only observed during post-monsoon with higher percentage. Fish egg and larvae were commonly encountered during the course of investigation in the entire year.

Population density and biomass: The standing stock of zooplankton during the present study is presented by the numerical abundance (Organisms m^{-3}). The population size of zooplankton discerned significant tidal variations (Fig. 2 and Table 2). In postmonsoon, highest plankton densities of 885 Org. m^{-3} were observed during the high tide, while lowest density of 287 Org. m^{-3} was observed during mid tide. The mean density in post-monsoon was 532 Org.m^{-3}. The population density in Pre-monsoon varied between 75 org. m^{-3} (mid tide) and 196 org. m^{-3} (high tide) with a mean density of 137 Org. m^{-3}. The highest zooplankton density was encountered during mid tide with 456 Org. m^{-3} and lowest density of 52 Org. m^{-3} was encountered during low tide of monsoon. The mean density in monsoon was 231 Org. m^{-3}. Average zooplankton biomasses were 1.50, 0.32, 0.59 mL m^{-3} during Postmonsoon, Premonsoon and monsoon respectively. Maximum displacement volume (3.00 mL m^{-3}) was recorded in mid tide of postmonsoon.

Relative abundance: In marine and estuarine waters, the zooplankton populations are always represented by a mixture of Tintinnids, Siphonophores, Polychaetes, Crustaceans, Molluscs, Chaetognath, Larvacea together with an array of larval forms. During the present study, for the purpose of computing relative abundance, the zooplankton population were first divided into two major groups: the holoplankton and meroplankton.

The holoplankton were represented mainly by copepods, other crustaceans (Decapods, mysids, cumaceans, amphipods, isopods, ostracods, cladocerans, euphausiids etc) and non crustaceans which included the appendicularians from tunicates, cnidarians (hydroidomedusae, siphonophores and ctenophores), protozoans, gastropods, polychaetes and chaetognaths etc (Fig. 3). Undermicroscope photographs of some identified zooplankton species are provided in Fig. 4.

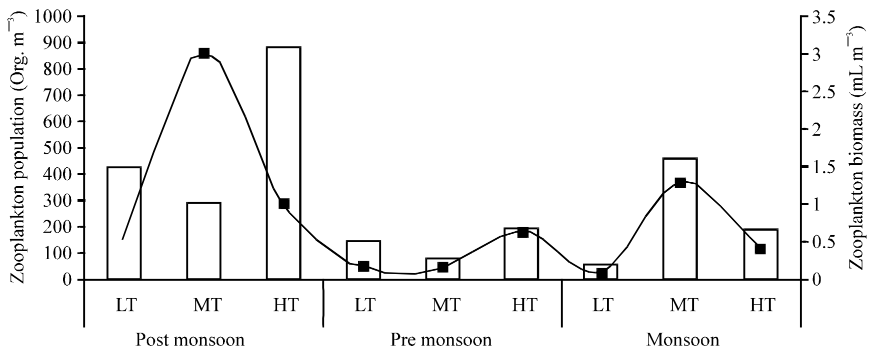

Fig. 2: Seasonal and tidal variations in population density and biomass of zooplankton, HT: High Tide; MT: Mid Tide; LT: Low Tide

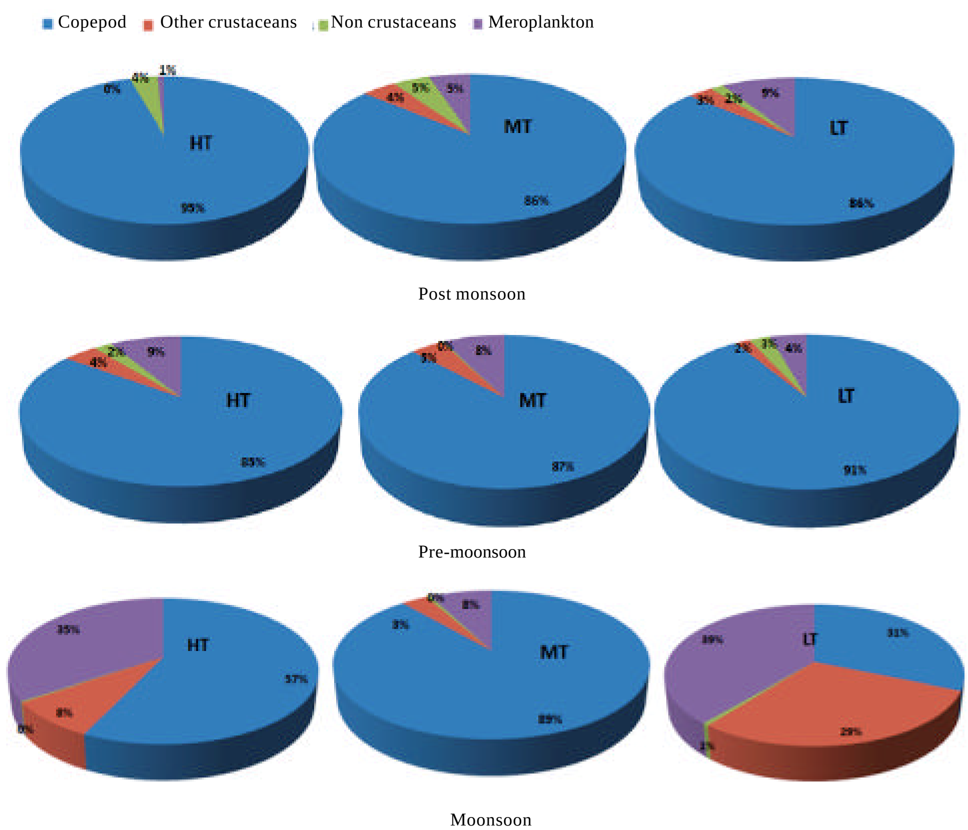

Fig. 3: Seasonal relative abundance of major zooplankters in Mahanadi estuary

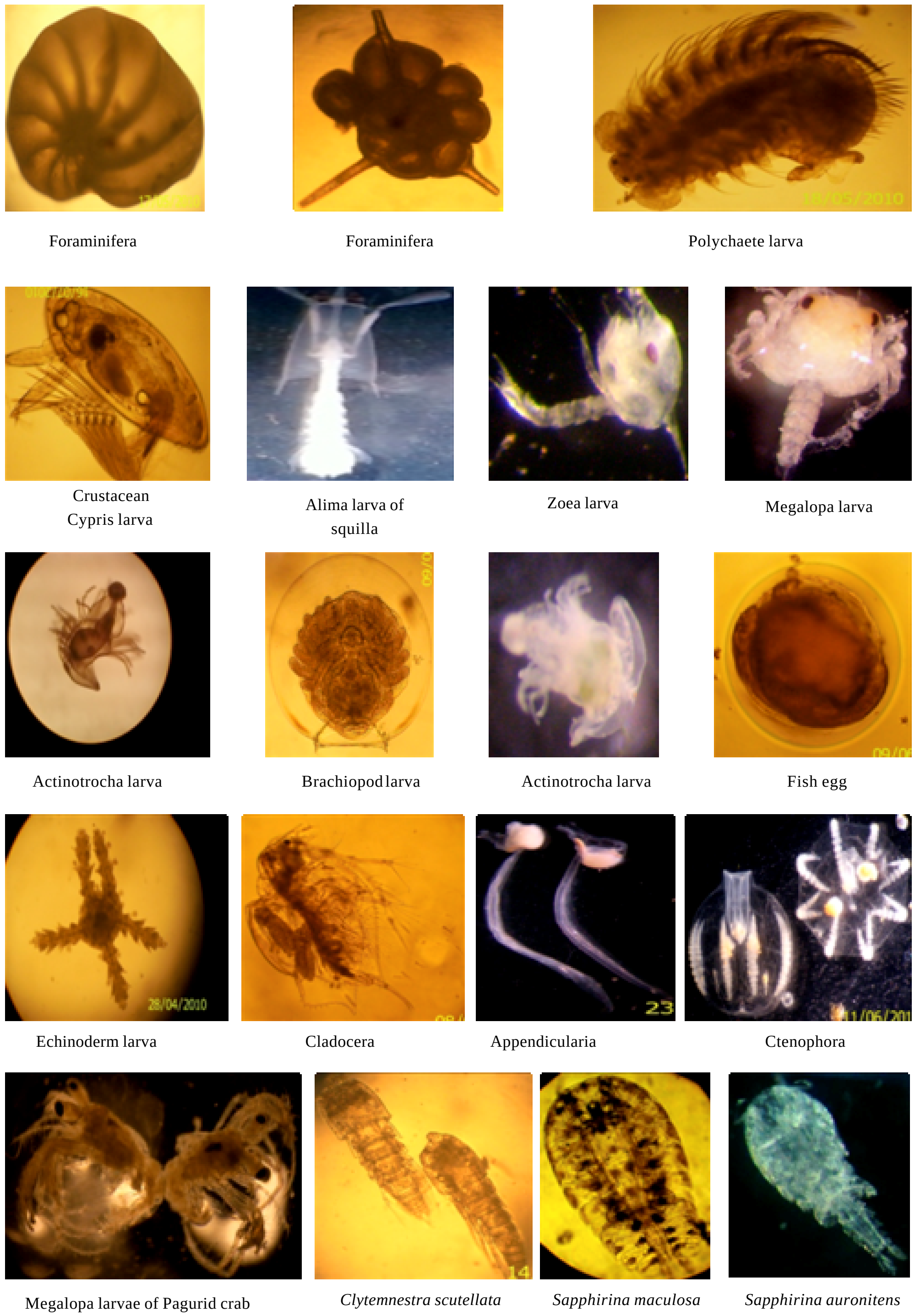

Fig. 4 : Undermicroscope photographs of some zooplankton species encountered during the study

DISCUSSION

Temperature, which always remains as a covariate with other environmental factors, considerably influences the physico-chemical and biological characteristics of an aquatic ecosystem. The water temperature again depends very much upon the air temperature and amount of radiant energy reaching the surface. Our results showed that water temperature in all the seasons almost followed the air temperature. The salinity acts as a limiting factor in the distribution of living organisms in estuaries and brackish water lagoons. During the entire survey the trend of salinity variation depicted heterogeneous situation. The observed dissolved oxygen concentrations were within the acceptable range (McNeely *et al.*, 1979). The pH values remained alkaline during the period of observation.

Presently recorded zooplankton consisted of 102 forms including 16 larvae from the Mahanadi estuary. Studies on zooplankton communities, especially copepods are very important in assessing the health of aquatic ecosystem. The abundance and variations in zooplankton of estuaries are mainly related with salinity regime. Among the five orders of the subclass-copepoda, the order calanoida represented by the bulk of copepods with 33 species. This may be due to their high reproductive capacity, quick larval development (Perumal *et al*, 2009). The copepods like *Subeucalanus mucronatus, S. subcrassus, Sapphirina maculosa, S. auronitens* were recorded for the first time from marine and estuarine ecosystem of Odisha coast. However, the appearance of three species of chaetognaths and tunicates in the estuary indicating their recruitment into the estuary from adjacent Bay of Bengal through tidal incursion. Occurrence of different zooplankton taxa *viz.* hydroidomedusae, siphonophores, and pelagic tunicates like appendicularians is dependent upon the state of tide which corroborates earlier findings (Goswami *et al.*, 1979). Chaetognaths thrived in the estuary only during high saline period (23.47 PSU) has also been reported by previous workers (Sarkar *et al.*, 1986). Availability of 16 different types of larval forms dominated by crustacean larvae depicts the conduciveness of estuary during the whole period for breeding and spawning of shell fishes, crustaceans in the estuary. Similar observations were also made by Perumal *et al.* (2009) and Tiwari and Nair (1993). Larvae of crustaceans were found throughout the year and this type of observation was also reported from the estuarine ecosystem of Odisha (Gouda and Panigrahy, 1995; Mishra and Panigrahy, 1999). During the present study, zooplankton population density is positively related with zooplankton biomass. Further intensive and long term studies are required to evaluate the secondary productivity of the estuary on a seasonal, annual basis and also elucidate the plankton biodiversity in the estuary.

CONCLUSION

Total seasonal and tidal zooplankton diversity of the study area was explored during the study. During postmonsoon and premonsoon zooplankton density dominated during high tide indicating the dominance of marine forms. Presence of 16 different larval forms dominated by crustacean members notifies that Mahanadi estuary acts as a breeding ground for shell fishes. During the present study, zooplankton population density was positively related with zooplankton biomass which denotes equal size distribution of species. From the present study it can be safely concluded that Mahanadi estuary plays a major role in coastal food chain in terms of regulating the zooplankton. Further the zooplankton composition signifies a healthy environment in this estuarine zone. The present study will act as a baseline reference for future environmental impact assessment work on this important ecosystem.

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