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Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India

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Abstract: *The results of an investigation carried out during October 2005 to September 2006 on hydrography, composition and community structure of phytoplankton and zooplankton including chlorophyll 'a' (Chl-a) content and primary productivity (PP) at the Kaduviyar estuary (Southeast coast of India) are reported. Air and surface water temperatures (°C) varied from 23 to 29 and from 24 to 31 respectively while the light extinction coefficient values (LEC) ranged between 0.15 and 0.59. Salinity values (‰) varied from 4 to 34 and the pH ranged between 7.8 and 8.3. Variation in dissolved oxygen content was from 3.06 to 5.63 mg l^{-1}. The ranges of inorganic nutrients (µM) viz., nitrate, nitrite, phosphate, silicate and ammonia were: 0.36-12.65; 0.06-1.86; 0.06-4.57; 17.96-235.06 and 0.001-0.75 respectively. The ranges of Chlorophyll 'a' (mg m^{-3}) and the primary productivity (mgC$m^{-3}$$hr^{-1}$) values were: 3.4-12.8 and 55-119 respectively. Presently, 85 phytoplankton species representing different classes viz: Bacillariophyceae (58); Dinophyceae (16); Cyanophyceae (7); Chlorophyceae (3) and Chrysophyceae (1) were recorded. The phytoplankton density varied from 14,135 to 74,697 cells l^{-1}, with peak diversity (3.46 bits ind.$^{-1}$) during premonsoon season. The maximum density was found during summer season coinciding with the stable hydrographical conditions. Totally 92 species of zooplankton besides 18 larvae were recorded and the copepods formed the dominant group. The occurrence of most of the zooplankton species showed a distinct seasonal pattern, which was closely associated with the species-specific environmental conditions. That way the environmental factors exert major influence on the species composition, abundance and diversity of zooplankton. The zooplankton density (org. l^{-1}) ranged between 4342 and 14,002 and between 4867 and 15,816 at stations 1 and 2 respectively. Kaduviyar estuarine waters were very rich in zooplankton diversity (bits ind.$^{-1}$) viz: 5.29 at Station 2 which was slightly higher than 5.27 at Station 1. Higher values of zooplankton density and species diversity were found during premonsoon and summer seasons and which showed positive correlation with salinity. The seasonal distribution and abundance of plankton are discussed in relation to hydrographical parameters.*

Key words: *Nutrients, Diversity, Phytoplankton, Zooplankton, Kaduviyar estuary, Nagapattinam*
PDF of full length paper is available online

Introduction

Estuaries are economically important ecosystems for fisheries in tropical regions (Kawabata *et al*., 1993) and they act as a transitional zone between land and sea (Bardarudeen *et al*., 1996). Phytoplankton initiates the marine food chain, by serving as food to primary consumers like zooplankton, shellfish and finfish (Sridhar *et al.,* 2006; Mathivanan *et al.,* 2007; Tas and Gonulol, 2007; Saravanakumar *et al.,* 2008). Biomass and productivity of phytoplankton in different size ranges are important factors regulating the productivity of higher tropic-level organisms. The pelagic algal communities make important contributions to the smooth functioning of estuarine ecosystem (Kawabata *et al*., 1993). Phytoplankton species distribution shows wide spatio-temporal variations due to the differential effect of hydrographical factors on individual species and they serve as good indicators of water quality including pollution (Gouda and Panigrahy, 1996).

Tropical aquatic ecosystems are the most productive areas with rich zooplankton population (Robertson and Blabber, 1992; Saravanakumar *et al*., 2007b). Information on species diversity, richness, evenness and dominance evaluation on the biological components of the ecosystem is essential to understand detrimental changes in environs (Krishnamoorthy and Subramanian, 1999). Zooplanktons which are ubiquitous in distribution form a vital link for turnover of organic matter and transfer from primary producers like diatoms to secondary consumers like fishes. The rate of zooplankton production can be used as a tool to estimate the exploitable fish stock of an area (Tiwari and Nair, 1991). Zooplankton provides an important food source for larval fish and shrimp in natural waters and in aquaculture ponds. It has been reported that in many countries the failure of fishery was attributed to the reduced zooplankton especially copepod population (Stottrup, 2000).

Species composition and seasonal variation in phyto and zooplankton abundance has been studied in other regions of Indian coastal waters (Perumal *et al.,* 1999; Krishnamoorthy and Subramanian, 1999; Rajasegar *et al.,* 2000; Gopinathan *et al*., 2001; Godhantaraman, 2001; Geetha Madhav and Kondalarao, 2004; Ashok Prabu *et al*., 2005; Thillai Rajasekar *et al*., 2005; Tiwari and Chauhan, 2006; Sridhar *et al*., 2006; Mathivanan *et al.,* 2007; Saravanakumar *et al*., 2008). Present study deals with the

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species composition and community structure of plankton from inshore waters of Kaduviyar estuary in relation to hydrography, for the first time.

Materials and Methods

The river, Kaduviyar is situated near Nagapattinam town on the east (Coromandel) coast of India (Station 1: Lat 10° 45' N, Long 79° 96' E; Station 2: Lat 10° 45 N Long 79° 50'E) (Fig. 1). The Kaduviyar has its source in another major river, 'Cauvery' of Tamil Nadu. The Kaduviyar estuary has a year-round connection with the sea and is subjected to semidiurnal tides with maximum tidal amplitude of about 1m. It flows (from western part of Tamil Nadu) for a distance of 380 km through area of red, sandy, leached and laterised black soil in a loamy red soil and finally joins with the Bay of Bengal. The width of the estuary at the mouth is about 85 m and the tidal flushing extends to a distance of about of 10 km. For the present study, two sampling sites were chosen. The Station 1 is situated near the over bridge and the mouth of the estuary forms Station 2 (Fig. 1).

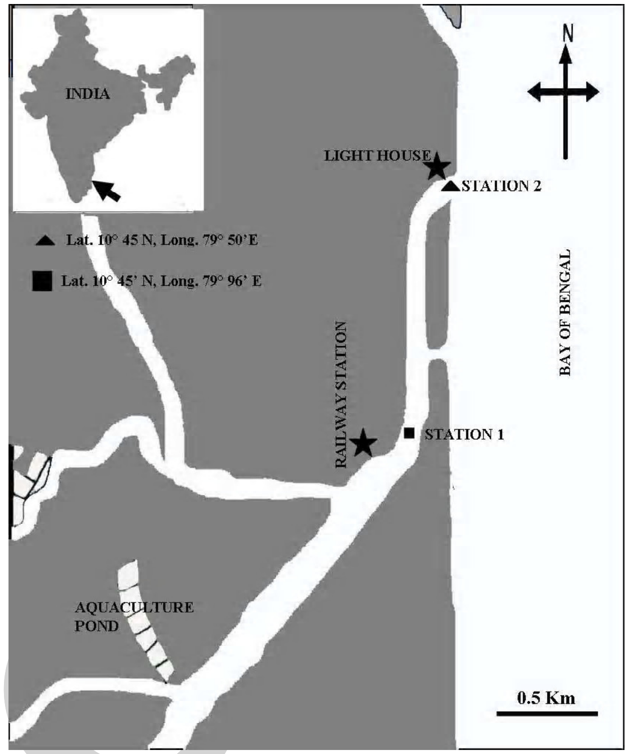

Fig. 1: Map showing the study area

Monthly samplings were made to record the physico-chemical, phytoplankton and zooplankton characteristics. Rainfall data was obtained from the local meteorological unit of Government of India located at Nagapattinam. Field data like temperature, salinity, dissolved oxygen and pH were measured during morning to noon. Atmospheric and surface water temperatures were measured using standard mercury filled centigrade thermometer. Light penetration in the water column was measured with the help of a Secchi disc and the light extinction coefficient (LEC) was calculated using the Pool and Atkins (1929) formula. Salinity was estimated with the help of a hand refractometer (Atago, Japan) and pH was measured using Elico pH meter (Model LC- 120). Dissolved oxygen was estimated by the modified Winkler's method (Strickland and Parsons, 1972). For the analysis of nutrients, surface water samples were collected in clean polyethylene bottles and kept in an ice box and transported immediately to the laboratory. The water samples were filtered using a Millipore filtering system (MFS) and analyzed for dissolved inorganic phosphate, nitrate, nitrite, reactive silicate and ammonia by adopting the standard methods described by Strickland and Parsons (1972).

Samplings of phytoplankton and zooplankton were carried out from the surface water, by towing the phyto and zooplankton nets (mouth diameter 0.35 m) made up of bolting silk cloths (No. 30 and 10, Mesh size -48 and 158 µm), for half an hour. The collected samples were preserved in 5% neutralized formalin for further analysis. For the quantitative analysis of phytoplankton, the settlement method described by Sukhanova (1978) was adopted. Numerical plankton analysis was carried out using Utermohl's inverted plankton microscope. Phyto and zooplankton were identified using the standard works of Hustedt (1930), Venkataraman (1939), Cupp (1943), Subrahmanyan (1946), Prescott (1954), Desikachary (1959 and 1987), Hendey (1964), Steidinger and Williams (1970), Taylor (1976), Anand *et al*. (1986) and Santhanam *et al*. (1987), Davis (1955), Kasturirangan (1963), Newell and Newell (1986), Deboyd Smith (1977), Wimpenny (1966), Todd and Laverack (1991) and Perumal *et al*. (1998). The phytoplankton analysed were assigned to major groups *viz*. diatoms, dinoflagellates, blue green algae and green algae. Chlorophyll 'a' concentration was estimated by following the method of Strickland and Parsons (1972). Primary production was estimated by adopting the light and dark bottle technique as described by Strickland and Parsons (1972) and the productivity values are expressed as $mgCm^{-3}hr^{-1}$. For the quantitative analysis of zooplankton, 500 l of water was filtered through a bagnet of same mesh size and the numerical plankton analysis was carried out using a binocular microscope. Biodiversity indices were calculated following the standard formulae: Biodiversity: $H' = -\Sigma\ Pi \log Pi$; $I = 1$; richness: $D = 1\text{-}C$; $C = \Sigma Pi^2$; $Pi = ni/N$ and evenness: $J' = H'/\log 2S$ (Shannon and Weaver, 1949; Gleason, 1922; Pielou, 1966). A calendar year was divided into four seasons *viz*., monsoon (October to December), postmonsoon (January to March), summer (April to June) and premonsoon (July to September) based on the northeast monsoon which is prevalent in the study area.

Correlation coefficients (r) were calculated for phyto and zooplankton density and physico-chemical parameters and the Analysis of Variance (F) tests were made for hydrological parameters in relation to stations and seasons. All these statistical analyses

Table - 1: Physico-chemical characteristics of the Kaduviyar estuary during (October 2005 to September 2006)

Parameter	Station	Oct. 2005	Nov.	Dec.	Jan. 2006	Feb.	March	April	May	June	July	August	Sep.
Rainfall (mm)		175	993	190	70	0	0	0	37	11	45	28	34
Atmospheric temp. (°C)	1	26.5	24	26	24	26	26.5	28	29	26	27	28	28
	2	27	23	25	24	25	28	29	29	27	28	28	29
Surface water temp. (°C)	1	28	24	26	27	26	27	29	29	28	29	28	27
	2	29	25	27	26	27	29	29	31	29	29	28.5	27
Salinity (‰)	1	11	0	4	7	22	25	31	30	29	29	30	28
	2	24	7	10	17	28	30	31	33	34	34	32	33
pH	1	8	7.8	8.2	7.9	8.2	8.3	8.3	8.1	8.2	8.1	8.2	8
	2	8.2	7.9	8.3	8.1	8.1	8.2	8.2	8.1	8.2	8.2	8.2	8.1
DO (mg l^{-1})	1	3.4	5.52	3.06	4.31	4.43	4.43	4.2	4.09	4.43	4.09	3.97	4.85
	2	4.88	5.63	3.18	4.65	4.54	4.65	4.31	4.77	4.54	4.31	4.2	4.21
Light extinction coefficient (cm)	1	0.41	0.43	0.59	0.31	0.34	0.28	0.18	0.21	0.27	0.34	0.35	0.37
	2	0.36	0.42	0.52	0.34	0.31	0.19	0.15	0.21	0.22	0.28	0.32	0.35
Nitrate (µM)	1	7.69	9.21	4.82	5.57	1.95	0.95	0.52	2.95	6.84	7.52	4.55	5.39
	2	5.41	12.65	8.15	2.10	2.41	0.83	0.36	2.50	5.79	4.82	2.07	3.68
Nitrite (µM)	1	0.74	1.86	1.69	0.60	0.73	0.30	0.58	0.06	1.54	1.09	1.31	1.27
	2	0.23	1.78	1.66	0.49	0.72	0.07	0.47	0.91	1.22	0.95	1.03	1.32
Phosphate (µM)	1	4.57	3.58	2.29	2.93	1.60	0.89	0.56	0.06	1.25	3.83	2.03	3.64
	2	2.20	3.65	2.03	2.13	2.11	0.80	0.18	0.07	2.23	2.01	1.74	2.49
Silicate (µM)	1	147.00	120.92	229.50	235.06	177.76	44.00	23.24	44.85	31.38	38.42	35.99	192.22
	2	80.16	65.68	227.01	201.33	173.97	57.21	17.96	26.91	19.65	25.88	27.21	159.41
Ammonia (µM)	1	0.22	0.08	0.23	0.05	0.09	0.19	0.01	0.09	0.54	0.42	0.43	0.25
	2	0.27	0.08	0.75	0.04	0.07	0.23	0.001	0.07	0.16	0.01	0.20	0.11

were performed using SPSS statistical software (Version 11.5 for Windows, SPSS, Chicago, IL, USA).

Results and Discussion

Hydrography: Total rainfall of 1575 mm was recorded from October, 2005 to September, 2006. It varied from 11 to 993 mm and rain did not occur during February to April (Table 1). Rainfall is the most important cyclic phenomenon in tropical countries as it brings important changes in the hydrographical characteristics of the estuarine environment. In the present study, the peak values of rainfall were recorded during the monsoon month of November. The rainfall in India is largely influenced by two monsoons *viz.*, southwest monsoon on the west coast, northern and northeastern India and by the northeast monsoon on the southeast coast (Perumal, 1993). On the other hand tidal rhythm, water current and evaporation in summer produced only little variation in those parameters. Maruthanayagam and Subramanian (1999) have also reported the occurrence of bulk of rainfall during northeast monsoon season along the southeast coast of India.

Air and surface water temperature values (°C) varied from 23 to 29 and from 24 to 31 respectively (Table 1). The surface water temperature showed an increasing trend from December through April and was influenced by the intensity of solar radiation, evaporation, freshwater influx and cooling and mix up with ebb and flow from adjoining neritic waters. The observed low value of November was due to strong land sea breeze and precipitation and the recorded high value during summer could be attributed to high solar radiation (Das *et al*., 1997; Karuppasamy and Perumal, 2000; Govindasamy *et al*., 2000; Senthilkumar *et al*., 2002; Santhanam and Perumal, 2003). The observed spatial variation in temperature could be due to the viable intensity of prevailing streams and the resulting mixing of water (Reddi *et al*., 1993). Statistical analysis showed a positive correlation (r=0.712 at Station 1 and r = 0.812 at Station 2) between air and surface water temperature for both stations.

The salinity acts as a limiting factor in the distribution of living organisms and its variation caused by dilution and evaporation is most likely to influence the fauna in the coastal ecosystem (Balasubramanian and Kannan, 2005; Sridhar *et al*., 2006). Presently wide salinity variations were observed between two stations and during different seasons (Table 1). Generally, changes in the salinity in the brackishwater habitats such as estuaries, backwaters and mangroves are due to the influx of freshwater from land run off, caused by monsoon or by tidal variations. This is

Table - 2: List of phytoplankton species recorded at Kaduviyar estuary (October 2005 -September 2006)

Bacillariophyceae (Diatoms)	*Navicula* sp.	**Dinophyceae (Dinoflagellates)**
Asterionella glacialis Castracane	*N. henneydii* W.Smith	*Amphisolenia bidentata* Schroder
Bacillaria paradoxa Gmelin	*Nitzschia* sp.	*Ceratium* sp.
Bacteriastrum comosum Pavillard	**N. longissima *(Brebission) Ralfs***	*C. furca* (Ehrenberg) Claparede & Lachmann
B. hyalinum Lauder	*N. seriata* Cleve	*C. fusus* (Ehrenberg) Dujardin
Odontella sinensis (Greville) Grunow	*Netrium digitus* Ehrenberg	*C. extensum* (Paul.) Balch
O. mobiliensis *(Bailey) Grunow*	*Pediastrum simplex* Meyen	*C. macroceros* (Ehrenberg) Cleve
O. heteroceros Grunow	*P. duplex* Meyen	*C. trichoceros* (Ehrenberg) Kofoid
O. reticulum (Ehrenberg) Boyer	*Planktoniella sol* (Wallich) Schutt	*C. tripos* (O.F.Muller) Nitzsch
Bellerochea malleus (Brightwell) Van Heurck	*Pleurosigma sp.*	*Dinophysis caudata* Saville-Kent
Chaetoceros sp.	*Pleurosigma angulatum (Kuetz.) W. Smith*	*Dinophysis* sp.
Chaetoceros affinis Lauder	*P. elongatum* W. Smith	*Noctiluca scintillans* Sch. (Macarthey) Ehrenberg
C. curvisetus Cleve	*P. directum* Grunow	*Ornithocercus steinii* Sch
C. diversus Cleve	*P. normanii* Ralfs	*Prorocentrum micans* Ehrenberg
C. coarctatus Lauder	*Rhizosolenia alata* (Cleve) Grunow	*Protoperidinium* sp.
C. peruvianus Brightwell	*R. robusta* Norman	*P. oceanicum* (Van Hoffer) Balech
Coscinodiscus centralis Ehrenberg	*R. cylindrus* Cleve	*Pyrophacus steinii* (Schiller) Wall & Dale
C. gigas Ehrenberg	*R. imbricate* (Cleve) Schroder	**Cyanophyceae (Blue-greens)**
C. radiatus Heurck	*R. styliformis* Brightwell	*Anabena* sp.
C. exentricus Ehrenberg	*Skeletonema costatum* (Grev.) Cleve	*Lyngbya* sp.
C. granii Gough	*Stephanophyxis palmeriana (Grev.) Grunow*	*Microcystis* sp.
Cyclotella striata *(Kuetzing) Grunow*	*Streptothaeca indica* Karsten	*Nostac* sp.
Diploneis sp.	*Thalassionema nitzschioides* (Grunow) Meresch	*Oscillatoria* sp.
Ditylum brightwellii (West) Grunow	*Thalassiosira subtilis* (Ostenfeld) Gran	*Spirulina major* Kutz
Eucampia zoodiacus Ehrenberg	*Thalassiothrix frauenfeldii* (Grunow) Hallegraeff	*Trichodesmium erythraeum* Ehrenberg
Fragillaria sp.	*Triceratium favus* Ehrenberg	**Chlorophyceae (Greens)**
Gyrosigma balticum (Ehrenberg) Rabenhorst	*T. robertsianum* Greville	*Chlorella* sp
Hemidiscus hardmannianus H.Peragallo	*T. reticulatum* Ehrenberg	*Spirogyra* sp
Hemiaulus sinensis Greville		*Volvox* sp
Leptocylindrus danicus *Cleve*		**Chrysophyceae (Silicoflagellate)**
Lauderia sp.		*Dichtyocha* sp

presently evidenced by the negative correlation (r=-0.696 at Station 1 and r=-0.746 at Station 2) obtained between salinity and rainfall. Further, salinity is also influenced by the higher temperature as is evident from the obtained significant positive correlation with temperature. The salinity was found to be high during summer season and low during the monsoon season at both the stations. The recorded higher values (34.0‰) could be attributed to the low amount of rainfall, higher rate of evaporation and also due to neritic water dominance, as reported by earlier workers in other areas (Govindasamy *et al*., 2000; Gowda *et al.,* 2001; Rajasegar, 2003). During the monsoon season, the rainfall and the freshwater inflow from the land in turn moderately reduced the salinity (4.0‰), as reported by Saisastry and Chandramohan (1990) in the Godavari estuary; Mitra *et al.* (1990) in the bay of Bengal and Satpathy (1996) in coastal waters of Kalpakkam.

The light extinction coefficient values ranged between 0.15 cm (summer) and 0.59 cm (monsoon) (Table 1) and the recorded high monsoon value could be due to the low intensity of solar radiation and higher concentration of dissolved organic matter and suspended sediments. Further, inundation of freshwater discharge and bottom sediment could also be the important factors in governing light penetration (Sampathkumar and Kannan, 1998). The observed low summer value could be due to the higher solar penetration, clean water condition and low runoff (Kannan and Kannan, 1996), as has been supported by the positive correlation between light extinction coefficient and rainfall.

Hydrogen ion concentration (pH) in surface waters remained alkaline throughout the study period at all the stations with summer maximum (8.3) and monsoon minimum (7.8) (Table 1). Generally, its seasonal variation is attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, low primary productivity, reduction of salinity and temperature and decomposition of organic matter (Karuppasamy and Perumal, 2000; Rajasegar, 2003; Paramasivam and Kannan, 2005). The recorded high summer pH might be due to the influence of seawater penetration and high biological activity (Das *et al*., 1997) and due to the occurrence of high photosynthetic activity (Subramanian and Mahadevan, 1999). The statistical analysis also revealed that salinity show highly significant negative correlation with rainfall.

Variation in dissolved oxygen content was from 3.06 to 5.63 mg l^{-1} (Table 1). It is well known that the temperature and salinity affect the dissolution of oxygen (Vijayakumar *et al.*, 2000; Saravanakumar *et al.*, 2007a,b). In the present investigation, higher values of dissolved oxygen were recorded during monsoon months at all the stations. Season-wise observation of dissolved oxygen showed an inverse trend against temperature and salinity. The observed high monsoonal values might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and the resultant freshwater mixing (Das *et al.,* 1997). Mitra *et al*. (1990) have mainly attributed seasonal variation of dissolved oxygen to freshwater flow and terrigenous impact of sediments.

Nutrients are considered as one of the most important parameters in the estuarine environment influencing growth, reproduction and metabolic activities of living beings. Distribution of nutrients is mainly based on the season, tidal conditions and freshwater flow from land source. The recorded highest nitrates value (12.65 µM) during monsoon season could be mainly due to the organic materials received from the catchment area during ebb tide (Das *et al*., 1997) Table 1. The increased nitrates level was due to fresh water inflow, mangrove leaves (litter fall) decomposition and terrestrial run-off during the monsoon season (Karuppasamy and Perumal, 2000; Santhanam and Perumal, 2003). Another possible way of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite formation (Rajasegar, 2003). The recorded low values (0.36 µM) during non-monsoon period may be due to its utilization by phytoplankton as evidenced by high photosynthetic activity and also due to the neritic water dominance, which contained only negligible amount of nitrate (Gouda and Panigrahy, 1995; Das *et al*., 1997; Govindasamy *et al*., 2000). Further, significant inverse relationship between rainfall and nutrients indicated that freshwater flow constituted the main source of the nutrients in the estuaries.

The recorded higher nitrite values during monsoon season (1.86 µM) could be due to the increased phytoplankton excretion, oxidation of ammonia and reduction of nitrate and by recycling of nitrogen and also due to bacterial decomposition of planktonic detritus present in the environment (Govindasamy *et al*., 2000). Further, the denitrification and air-sea interaction exchange of chemicals are also responsible for this increased value (Choudhury and Panigrahy, 1991) Table 1. The recorded low nitrite value (0.06 µM) during summer and pre-monsoon seasons may be due to less freshwater inflow and high salinity (Mani and Krishnamurthy, 1989; Murugan and Ayyakkannu, 1991).

The recorded high concentration of inorganic phosphates (4.57µM) during monsoon season might possibly be due to intrusion of upwelling seawater into the creek, which in turn increased the level of phosphate (Nair *et al*., 1984) Table 1. Further, regeneration and release of total phosphorus from bottom mud into the water column by turbulence and mixing also attributed to the higher monsoonal values (Chandran and Ramamoorthy, 1984). The low summer value (0.06 µM) could be attributed to the limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton (Senthilkumar *et al.,* 2002; Rajasegar, 2003). The variation may also be due to the processes like adsorption and desorption of phosphates and buffering action of sediment under varying environmental conditions (Rajasegar, 2003). Moreover, the weatherings of rocks soluble alkali metal phosphates, the bulk of which are carried into the estuaries are also responsible for the recorded higher values (Gowda *et al*., 2001). The addition of super phosphates applied in the agricultural fields as fertilizers and alkyl phosphates used in households as detergents can be other sources of inorganic phosphates during the season (Das *et al*., 1997; Senthil Kumar *et al*., 2002).

The silicate content was higher than that of the other nutrients (NO_3, NO_2 and PO_4) and the recorded high monsoon values (235.06 µM) may be due to heavy inflow of monsoonal freshwater derived from land drainage carrying silicate leach out from rocks. Further, due to the turbulent nature of water, the silicate from the bottom sediment might have been exchanged with overlying water in this estuarine environment (Govindasamy and Kannan, 1996; Rajasegar, 2003) (Table 1). Besides this, the dissolution of particulate silicon carried by the river, the removal of silicates by adsorption and co-precipitation of soluble silicate silicon with humic compounds and iron (Rajasegar, 2003). The observed low post-monsoonal values (17.96 µM) could be attributed to uptake of silicates by phytoplankton for their biological activity (Mishra *et al*., 1993; Ramakrishnan *et al.,* 1999).

Higher concentration of ammonia (0.75 µM) was observed during the monsoon season in Station 2 and summer season in Station 1. Lower values of ammonia (0.001µM) was found during the summer season in both stations (Table 1). The recorded higher concentration could be partially due to the death and subsequent decomposition of phytoplankton and also due to the excretion of ammonia by planktonic organisms (Segar and Hariharan, 1989).

Primary productivity: Presently recorded high summer productivity could be attributed to the neritic element domination, high light intensity, clear water condition and availability of nutrients, as reported earlier by Gopinathan *et al*. (1994) and Thillai Rajasekar *et al*. (2005).

The primary productivity values ($mgCm^{-3}hr^{-1}$) ranged between 55 and 119 during monsoon and summer seasons respectively (Fig. 2). As the salinity and other hydrological parameters were in stable condition during summer the phytoplankton production was more (Nayar and Gowda, 1999; Rajesh *et al*., 2002).

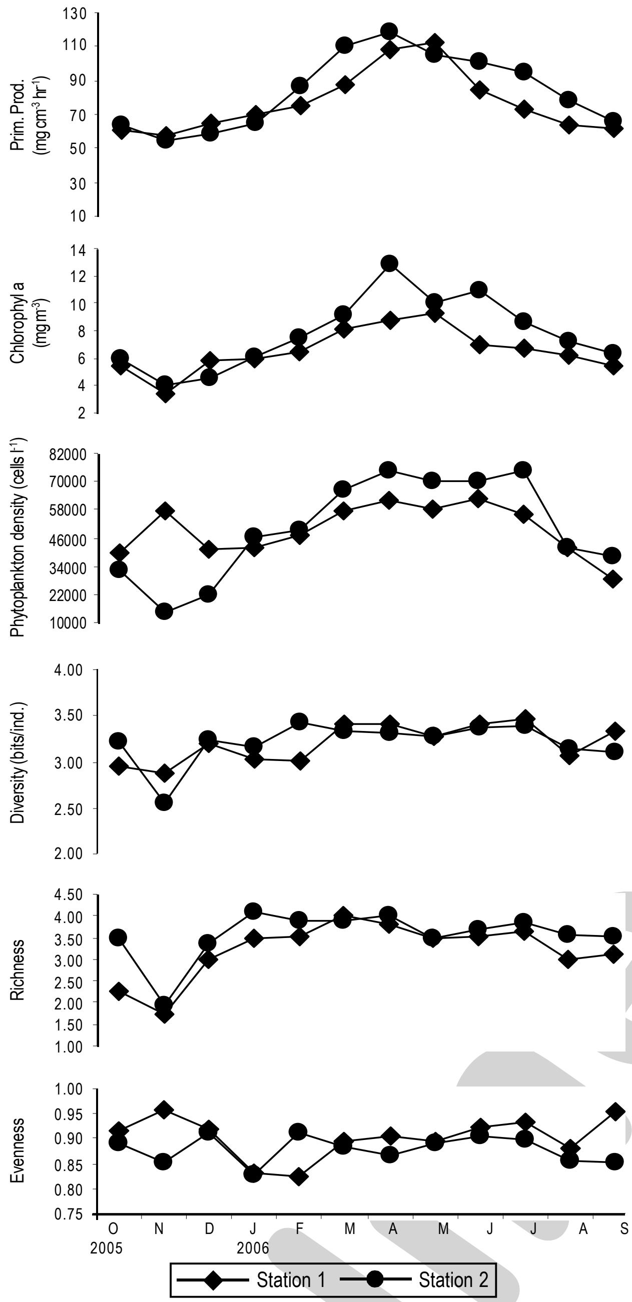

Fig. 2: Seasonal variations of primary productivity, Chlorophyll a, phytoplankton population density, diversity, richness and evenness recorded during 2005 to 2006

Higher primary productivity was observed during the summer season, because of high population density of phytoplankton and this higher density could also be due to neritic element domination, higher salinity and surface water temperature, clear water conditions besides availability of nutrients (Thillai Rajasekar *et al*., 2005). The recorded low primary productivity could be related to the wash of the phytoplankton to the neritic region by the monsoonal flood besides reduction of salinity, which could have affected the phytoplankton population (Rajasegar *et al*., 2000; Gowda *et al*., 2001; Thillai Rajasekar *et al*., 2005).

The observed high primary productivity during summer and southwest monsoon seasons may be due to increased radiation (Mani, 1992) and is supported by the positive correlation with the salinity. The increase in respiration in the samples collected during northeast monsoon season may be due to the mixing of land drainage, which carries a lot of organic substances, resulting in the possibility of biological oxidation (Subramanian and Mehadevan, 1999). In addition, the low values of primary productivity recorded during monsoon season could be due to the cloudy weather and allochthonous matter brought down by heavy downpour drained from surrounding areas and consequent high turbidity (Rajasegar *et al*., 2000).

The chlorophyll *a* (mg m^{-3}) ranges for stations 1 and 2 were 3.4-9.3 and 4.0 -12.8 (Fig. 2). A higher value of chlorophyll *a* was recorded during summer and the low value was observed during monsoon. The recorded low monsoonal values could be due to anthropogenic effects as evidenced by its positive correlation with salinity and may also is due to freshwater discharges from the rivers (dilution), causing turbidity and less availability of light (Kawabata *et al*., 1993; Godhantaraman, 2002; Thillai Rajasekar *et al*., 2005).

Composition and community structure of phytoplankton: Out of 85 species, 58 species of diatoms (Bacillariophyceae), 16 species of dinoflagellates (Dinophyceae), 7 species of blue greens (Cyanophyceae), 3 species of green algae (Chlorophyceae) and a species of silicoflagellates (Chrysophyceae) were found. Among the various species *Odontella sinensis*, *Thalassiothrix frauenfeldii, Skeletonema elongatum* and *Bacteriastrum comosum* were the most abundant forms. In general, the distribution and abundance of phytoplankton in tropical waters, varied remarkably due to the seasonal environmental fluctuations, and these variations are well pronounced in the sheltered system of estuarine waters. Percentage contribution of each group of phytoplankton was in the following order: Diatoms>Dinoflagellates>Blue greens>Greens> Silicoflagellate.

Phytoplankton species composition was comparatively more in Station 2 than in Station 1. Generally, diatoms were found to be dominant in Kaduviyar mouth waters, which could well thrive in widely changing hydrographical conditions (Mani, 1992; Tiwari and Nair, 1998; Rajasegar *et al*., 2000; Gopinathan *et al*., 2001; Gowda *et al*., 2001; Senthilkumar *et al*., 2002).

Presently observed high population density and species diversity during summer and premonsoon season might be due to the predominance of diatoms *viz.*: *Thalassiothrix frauenfeldii, Odontella sinensis, Bacteriastrum comosum, Chaetoceros affinis, Coscinodiscus centralis, Ditylum brightwelli* and *Skeletonema costatum*. The phytoplankton abundance during summer season could be attributed to the increased salinity, pH, high temperature and high intensity of light penetration during the season (Mani and Krishnamurthy, 1989; Saravanakumar *et al.*, 2008).

The abundance of phytoplankton was lowest during monsoon months, when the water column was remarkably stratified to a large extent because of heavy rainfall, high turbidity caused by run-off, reduced salinity, decreased temperature and pH, overcast sky and cool conditions. However, during this season, freshwater algal forms like *Anabaena* sp, *Oscillatoria* sp, *Chlorella* sp, *Nostoc* sp, *Lynbya* sp, *Spirogyra* sp *Volvox* sp *Spirulina major* and *Microcystis* sp. were noticed. The phytoplankton counts were high during southwest monsoon season as reported in some of the previous studies in Bay of Bengal (Marichamy *et al.*, 1985). Similar observations were earlier reported by Patterson Edward and Ayyakkannu (1991); Gouda and Panigrahy (1996) and Rajasegar *et al.* (2000). This is being supported by Ei-Gindy and Dorghan (1992) who stated that phytoplankton and their growth depend on several environmental factors, which are variable in different seasons and regions. This kind of cyclic change in the species composition of phytoplankton was a characteristic feature of the Pichavaram coastal mangroves (Mani, 1992).

The ranges of phytoplankton population density (cells l^{-1}) were: 28,797-62,900 (Station 1) and 14,135-74,697 (Station 2) (Fig. 2). The observed high density during the summer could be attributed to more stable hydrographical conditions prevailed during that period. Station 2 showed comparatively high population density due to high nutrient concentrations and optimal salinity (Gouda and Panigrahy, 1996; Rajasegar *et al.*, 2000). Further, the density showed a negative correlation with nutrients, which might be due to the utilization of nutrients by phytoplankton. It was noticed that the density value coincided with the values of species richness. The population density was found to be higher in summer season at both the stations but the species diversity values were found to be higher only during premonsoon season and it may be due to the occurrence of allochthonous species (Senthilkumar *et al.*, 2002; Thillai Rajasegar *et al.*, 2005).

The ranges of species diversity, richness and evenness at stations 1, and 2 were 2.55-3.46, 1.73-4.08 and 0.82-0.96 respectively (Fig. 2). The least values of biodiversity indices were recorded during monsoon season, but were higher during other periods. A total of 85 species of phytoplankton identified in Kaduviyar estuary are often common and contributed significantly to the total abundance of phytoplankton, as reported in other regions (Kannan and Vasantha, 1992; Gowda *et al.*, 2001; Senthilkumar *et al.*, 2002). Thillai Rajasekar *et al.* (2005) reported the number of phytoplankton species increased consistently towards the outer region of the Bay of Bengal, where the salinity was high.

The observed species richness values from both the stations is similar to that of phytoplankton population density and the maximum richness values were recorded during the postmonsoon season.

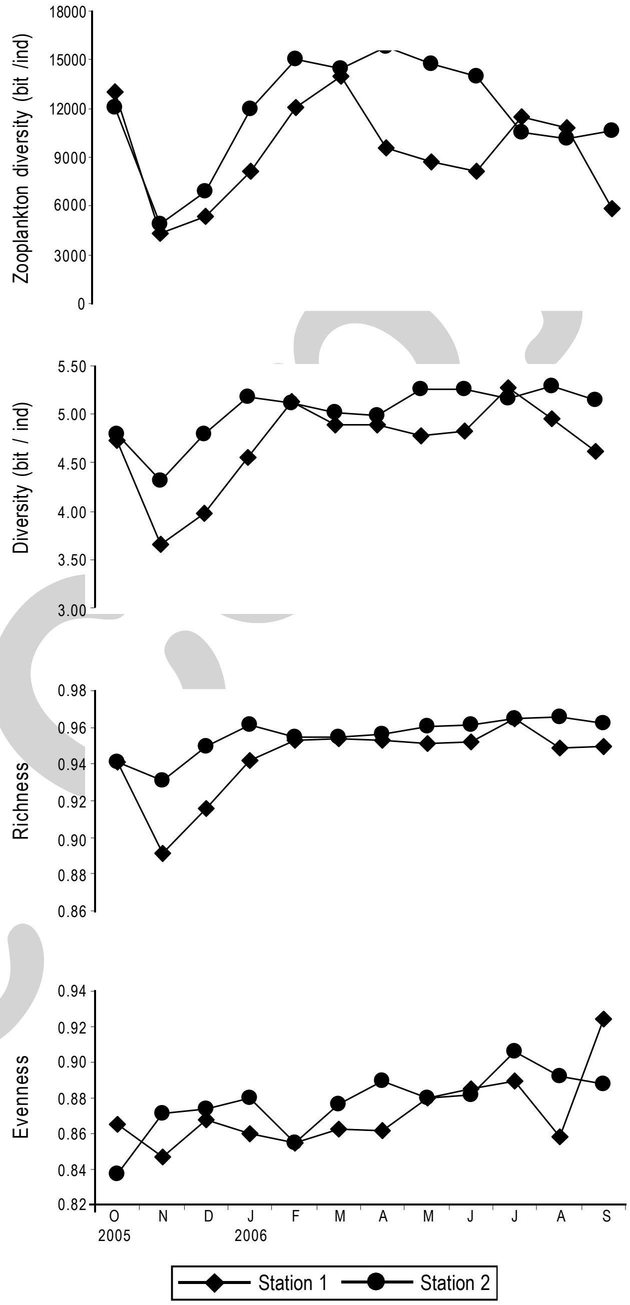

Fig. 3: Seasonal variations of zooplankton population density, diversity, richness and evenness recorded during 2005 to 2006

The low richness was recorded during the monsoon season (Rajasegar *et al.*, 2000). Higher and lower species richness recorded during postmonsoon and monsoon seasons respectively could be correlated with the recorded lower and higher salinity values, as reported by Mani (1992). This is further evidenced by the positive correlation obtained between salinity and species richness (r=0.637 at Station 1 and r=0.599 at Station 2).

Composition and community structure of zooplankton: A total of 110 zooplankton including 18 larvae belonging to diverse groups *viz*., foraminifera (3), ciliata (15), hydrozoa (4), rotifera (12), chaetognatha (3), cladocera (3), copepoda (43), appendicularia (1), Salpidea (1), decapoda (2), amphipoda (1), mysidaceae (1), Doliolida (1), Pteropoda (1), Cumaceae (1) and larvae (18) were recorded.

At Station 1, 90 forms of zooplankton were recorded, the majority was formed by copepods (33), followed by 18 forms of larvae, 12 each to ciliata and rotifera, 3 cladocera, 2 each to foraminifera, decapoda, chaetognatha, 1 each to appendicularia, amphipoda, cumaceae, mysidacea, hydrozoan and pteropoda. At station 2, 98 zooplankton were represented by copepoda (43), rotifera (6), larvae (15), ciliata (16), hydrozon (4), 3 each to foraminifera, chaetognatha, 2 each to cladocera, and decapoda and 1 each to appendicularia, amphipoda, mysidacea and pteropoda. The percentage compositions of zooplankton were dominantly occupied by copepods followed by other groups at both the stations.

Presently recorded zooplankton consisted of 110 forms including 18 larvae from both the stations. The descending order of abundance of the various groups of zooplankton is as follows: Copepoda > Larvae > Ciliata > Rotifera > Hydrozoa > Cladocera > Chaetognatha > Foraminifera > Decapoda > Salpa and Doliolida > Amphipoda > Mysids larvae > Cumacea > Pteropoda.

Studies on zooplankton communities, especially copepods are very important in assessing the health of coastal ecosystems (Ramaiah and Nair, 1997). The abundance and variations in zooplankton of estuaries are mainly related with salinity regime. Among the 3 sub orders of the order-copepoda, the sub-order calanoida represented by the bulk of the copepods with 26 species. This may be due to their continuous breeding behaviour, quick larval development and that they adopt well to the widely changing environmental conditions of the estuary. Further, among the calanoids, *Acartia* spp. dominated the other forms throughout study period (Madhupratap, 1987) and that of *Oithona* spp. among cyclopoid was noticed (Mckinnon and Klumpp, 1998). Similar findings were earlier reported in Parangipettai coastal waters by Santhanam and Perumal (2003) who have pointed out that the abundance of *Oithona* spp was mainly due to its high reproductive capacity.

The most common species of copepods were *Paracalanus parvus, Acrocalanus gibber, A. gracilis, Acartia spinicauda, A, danae, A, erytharea and A. southwelli* from the Station 1 and 2, and *O. rigida, O. brevicornis, O. similis* from Station 1, *O. rigida, O. brevicornis, Eucyclops agilis, E. speratus, Paracyclops* sp., *Mesocyclops* sp, from the Station 2. Among the harpacticoid copepods, *Euterpina acutifrons* and *Microsetella norvegica* were present throughout the study period at both the stations. The abundance of these species might be due to the plentiful food availability as well as due to their continuous breeding nature, high reproductive capacity and the suitable environmental conditions of the ecosystem (Ramaiah and Nair, 1997; Santhanam and Perumal, 2003). Similar type of high species dominance of macrozooplankton have been reported from Mandovi and Zuari estuaries by Padmavathi and Goswami (1996) and Sai Sastry and Chandramohan (1995) from Godavari estuary.

The abundance of copepods steadily increased at both the stations from November to May with rising trend of salinity. With the onset of southwest monsoon (July-October), salinity dropped down and the population density also declined (Bhunia and Choudhury, 1982). The peak in copepod fauna during summer season could be attributed to the recruitment of neritic species through tidal influenced massive ingress of seawater into the estuary (Sujatha Mishra and Panigrahy, 1996). The important factors which controlled the distribution of copepods were rainfall, river discharge and decreased phytoplankton abundance due to increased turbidity (Bijoy Nandon and Abdul Azis, 1994). Moreover, many copepod species disappear during monsoon and species composition also changed, since they are mostly stenohaline (Eswari and Ramanibai, 2004). Further, the species composition is positively correlated with salinity showing that the community as a whole preferred high saline conditions.

Among the microzooplankton-tintinnids, the genus, *Tintinnopsis* was the most abundant one with 9 species *viz*., *Tintinnopsis cylindrica*, *T. beroidea, T. butschi, T. kofoidi, T. tocantinensis, T. tubulosa, T. minuta, T. mortensenii and T. bermudensis, Favella philippinensis* and *F. brevis*. Their predominance could be due to their high reproductive capacity and euryhaline nature (Govindasamy and Kannan, 1991). Similar observations were made by Krishnamurthy *et al*. (1995) and Godhantaraman (1994) in the Pichavaram mangroves and the adjacent Coleroon estuary. One of the characteristic features of the present observation was the relatively large occurrence of copepod nauplii, which could be attributed to high density of older stage copepods (Uye *et al*., 2000). Another reason could be the minor contribution made by rotifers, which was often specific to brackishwater environments (Godhantaraman, 2001).

Among the rotifers, *Brachionus* was the most abundant genus with 5 species (*B. calyciflorus, B. rubens, B. plicatilis, B. falcatus and B. caudatus*) and to lesser extent by *Keretella* sp, *Monostyla* sp, *Platyias quadricornis and Lecane inopinata,* as they are least tolerant to higher salinity. Similar observations have been made earlier from Pichavaram mangroves (Govindasamy and Kannan, 1991).

Lucifer hanseni representing decapoda was recorded at both the stations. This is in conformity with the findings of Padmavathi and Goswami (1996). The meroplanktonic organisms such as veligers of bivalves and gastropod, copepod nauplii and barnacle nauplii were commonly found in Kaduviyar estuary. The presence of more number of meroplankters indicates that the estuarine waters serve as a breeding and nursery grounds for a variety of fishes as reported earlier by Chandrasekaran and Natarajan (1993) and Tiwari and Nair (1993) from Pichavaram mangroves and Dharmatar creek.

The ranges of population densities (org. l^{-1}) of zooplankton were: 4342-14002 and 4867-15816 at Station 1 and 2 respectively (Fig. 3). The density of the zooplankton was comparatively high at Station 2. In the present study, minimum population density recorded during the monsoon seasons at both the stations and the maximum population density recorded during postmonsoon at station 1 and summer at Station 2. The recorded high densities might be due to the relatively stable environment condition, which prevailed during those seasons and great neritic elements presence from the adjacent sea could have also contributed to the maximum density of zooplankton. Further, salinity is the key factor influencing the distribution and abundance of zooplankton (Padmavathi and Goswami, 1996). The salinity showed positive correlation with zooplankton density (r=0.425 at Station 1 and r=0.716 at Station 2).

The recorded low monsoonal density could be due to the hydrographically washable environmental condition. The freshwater flood from the upstream causes great depletion of zooplankton population density during monsoon season. Padmavathi and Goswami (1996) have stated that the heavy flood changed the salinity, temperature and other environmental variables which inturn decreased the zooplankton density (Shanmugam *et al*., 1986). The presently recorded higher summer population densities of zooplankton coincided with the peak of phytoplanktonic density (Govindasamy and Kannan, 1991; Krishnamurthy *et al*., 1995). Higher population density with more number of copepods species were earlier observed by Rajagopalan *et al*. (1992) and Paulinose *et al*. (1998) in Gulf of Kachchh.

Species diversity variations were: 3.66-5.27 (Station 1) and 4.32-5.29 (Station 2) (Fig. 3). Species richness ranges were: 0.89-0.97 and 0.93-0.97 at Station 1 and 2 respectively (Fig. 3). The ranges of species evenness were: 0.85-0.92 and 0.84-0.91 at Stations 1 and 2 respectively (Fig. 3). The recorded high premonsoonal species diversity values may be due to the high zooplankton density that also indicated the stable high salinity values and phytoplankton density. The low species diversity was observed monsoon season, which could be attributed to heavy freshwater influx and low salinity (Govindasamy and Kannan, 1991; Godhandaraman, 1994; Prasad, 2003). This is supported by the obtained statistically significant r values between diversity and density (r=0.37 at Station 1 and r=0.75 at Station 2).

Presently maximum species richness was recorded during the premonsoon season. During this season, population density of the zooplankton also increased with increasing species richness (Santhanam and Perumal, 2003). Maximum evenness was recorded during the premonsoon season and low evenness was observed during the monsoon season. Population density, species diversity and species richness values were high during premonsoon along with high values of evenness index, suggesting the equal distribution of species during this season (Karuppasamy and Perumal, 2000). The statistical correlation values of evenness showed positive correlation with species richness and species diversity at both the stations. The results of analysis of variance (ANOVA) for the difference in zooplankton distribution between the stations are significant at 0.05% level.

The observed low zooplankton productivity during monsoon might be due to the non-availability of food, low temperature and low salinity. The disturbances of the food web and minimum production of plankton during the monsoon season have been observed in many Indian estuaries (Kannan and Kannan, 1996; Satpathy, 1996). During the monsoon, the salinity decreased to 4.0 owing to the inflow of freshwater. The low salinity would drastically affect the plankton abundance (Godhandaraman, 1994). In the present investigation, the increase or decrease of salinity in the water column exerts either a direct or an indirect effect in the appearance or disappearance of some forms and replacement by others. The second effect is probably due to the migration of some species from one station to another to avoid either low or high salinity. The indirect effect might be due to the scarcity of food caused by the fluctuations of salinity in the waters ultimately affecting the population abundance of zooplankton.

The present basic information of the phyto and zooplankton distribution and abundance would form a useful tool for further ecological assessment and monitoring of these coastal ecosystems of Kaduviyar estuary.

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