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Studies on Zooplankton Ecology from Kodiakkarai (Point Calimere) Coastal Waters (South East Coast of India)

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Abstract: The spatial, temporal and tidal dynamics of the zooplankton community of the Kodiakkarai (also known as point calimere) was studied from September 2006 to August 2007. The monthly sampling procedure included the measurement of hydrological parameters salinity, temperature, pH and the collection of zooplankton with plankton net (0.35 m mouth diameters), made up of bolting silk (Cloth No. 10; mesh size 158) for 20 min. The hydrographical parameters were found to very month-wise and station-wise. Air temperature showed summer peak and pre-monsoon, post-monsoon and monsoon decline and the variations were associated with the seasonal changes of meteorological events. Salinity was high during the post monsoon and summer seasons and low during the monsoon season at both stations and was mainly influenced by the rainfall pattern. pH was high during the monsoon and summer seasons and low during the monsoon and post-monsoon seasons at both stations and the rainfall mainly influenced the variation. Dissolved oxygen concentration was high during the monsoon season and low during the summer season at both stations. Distribution of dissolved nutrients also exhibited considerable seasonal due to the flooding and land runoff. The silicate concentration was especially found to be much higher than other nutrients. Among the 121 zooplanktonic forms recorded, the Copepoda formed the dominant group followed by larvae.

Key words: Nutrients, diversity, zooplankton, point calimere, hydrographical parameters, India

INTRODUCTION

The coastal zone is the link between ocean and land margins. The coastal ecosystems are involving in primary and secondary production, sustain the flora and fauna, store sediments and organic carbon, essential to the maintenance of food chains. The coastal ecosystems provide foods (fish and minerals) and services (natural defense against storms and tidal waves). The coastal ecosystems provide habitat to genetically, ecologically and economically valuable biological organisms (Ramachandran *et al*., 2000). Concern is expressed that many of these areas are now struggling to maintain their diversity due to drastic weather changes, the introduction of exotic species, global warming and very attractive for transport purposes and also for human settlement (De Jonge *et al*., 2002). Zooplankton organisms a very important step in the construction of modern oceanic food webs (Vannier *et al*., 2003). 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 that the failure of fishery was attributed to the reduced copepod productivity (Stottrup, 2000). Zooplanktonic organisms play a crucial role in marine food webs both in terms of biomass and energy fluxes by exploiting and recycling microscopic phytoplankton (Vannier *et al*., 2003). They produce massive quantities of nutrient-rich particles that constitute a permanent and exploitable resource for benthic communities (Butterfield, 2002). Furthermore, as prey for larger mid water secondary consumer, many of them also contribute directly to the food chain. Thus, the colonization of mid water niches by zooplankton organisms a very important step in the construction of modern oceanic food webs (Vannier *et al*., 2003). Small planktonic marine copepods are undoubtedly the most abundant metazoans on earth (Banse, 1995). Besides being the dominant grazers of phytoplankton, copepod communities in turn function as prey for higher trophic groups and are central in the cycling of organic matter in the pelagic zone (Verity and Smetacek, 1996). It is therefore important to include the state of these communities in any investigation on a marine system, whether in ecological studies or risk assessment of

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pollutants (Verity and Smetacek, 1996; Marcus, 2004). The Copepoda with high species richness in the sea is comprised of members occupying various feeding guilds, including herbivores (Guisande *et al*., 1996; Calbert *et al*., 2000), detritivores (Boak and Goulder, 1983; Gyllenberg, 1984; Steinberg *et al*., 1998), bacterivores (Gowing and Wishner, 1992; Turner and Roff, 1993; Webber and Roff, 1995), ciliates (Jonsson and Tiselius, 1990; Siaz and Kiorboe, 1995) and cyanobacteria consumers (Tokioka and Bieri, 1966; Ingolfsson and Olafsson, 1997), besides carnivores (Ohtsuka *et al*., 1987; Uye and Rayano, 1994; Kurashov, 1996). The microzooplanktonic forms like titinnids are an important component of marine food webs (Pierce and Turner, 1992), Planktonic ciliates are important in the transfer of material through coastal food webs and they act as a link between small phytoplankton and larger zooplankton (Reid *et al*., 1991).

Ciliates graze between 30-50% of primary production in many microzooplankton in temperate coastal waters (Pierce and Turner, 1992). Though a small community, they are much more abundant than foraminifera or radiolarians and there is a wealth of data on their ecology (Dolan, 2000; Dolan *et al*., 2002). The structure and organization of meroplankton communities are very important to determine the productivity and stock recruitment of commercially contributing harvestable resources in the marine ecosystem (Damotharan *et al*., 2007). During recent times marine calanoid copepods viz: *Acartia* sp. are being promoted as live food-organisms in some marine hatcheries. Marine copepods are natural feed which can act as alternatives or supplements to *Artemia nauplii* of doubtful nutritional suitability (Watanabe *et al*., 1983; Rajkumar *et al*., 2004; Rajkumar, 2003, 2006). Coastal marine ecosystems have an outstanding direct socio economic importance for many tropical coastal regions (Aksornkoae *et al*., 1993; Uthoff, 1996).

Some studies on the annual distribution patterns of zooplankton have been made in the Kodiakkarai (point calimere) coastal waters and adjacent biotopes like Tranquebar-Nagapattinam coastal waters (Anbhazhagan, 1988; Sampathkumar, 1992). Presently, an investigation has been made on the species composition and community structure of zooplankton from Kodiakkarai coastal waters in relation to hydrography of the area, south eastcoast of India.

MATERIALS AND METHODS

Kodiakkarai (also known as point calimere) located along the coramandal coast, Nagapattinam district of Tamil Nadu (station 1, Lat. 10°16°20 N; Long. 79°49°51 E and station 2 Lat.10°14°26 N; Long. 79°49°25 E) is bounded by a part of the bay of Bengal and the northeast and palk strait on the Southwest and which embraces a vast swamp area (Fig. 1). It is one of the most important bird and Black Buck sanctuaries in India and forest seen here extends over an area of 25 km^2 (Damotharan *et al*., 2007).

Fig. 1: MAO showing the study area

For the present study, two sampling sites were chosen. The station 1 is shoreline of 1 m depth and the 5 m depth of the sea is station 2 (Fig. 1). The different sampling sites representing ecologically different regions within the Kodiakkarai coastal waters were selected for the present study, as shown in station 1 (Fig. 1). This tidal zone is turbid shore zone with an average depth of 1 m in station 2. This coastal zone average depth is 5 m. Surface water samples were collected at monthly interval from the stations 1 and 2 for a period of one year from September 2006 to August 2007, for the estimation of various physico-chemical parameters.

Rainfall data were with the help of a refractometer (ATAGO, Hand Refractometer and Japan) obtained from the meteorological unit (Government of India) located at Vedaranyam. Temperature was measured using a standard centigrade thermometer. Salinity was estimated pH was measured using a ELICO Grip pH meter. Dissolved oxygen was estimated by the modified Winkler's method (Strickland and Parsons, 1972) and is expressed as mL L^{-1}. For the analysis of nutrients, surface water samples were collected in clean polyethylene bottles kept immediately in an icebox and transported to the laboratory. The collected water samples were filtered by using a Millipore filtering system and analyzed for dissolved inorganic nitrate, nitrite, phosphate and reactive silicate adopting the standard procedures described by Strickland and Parsons (1972) and are expressed in µm. Zooplankton samples were collected at monthly intervals from the surface waters by horizontal towing of plankton net (0.35 mouth diameter), made up of bolting silk (Cloth No. 10, mesh size 158 µm) for 20 min. These samples were preserved in 5% neutralized formalin and used for qualitative analysis. For the quantitative analysis of zooplankton, a known quantity of water (500 L) was filtered through a bagnet of same mesh size and the numerical plankton analysis was carried out using a binocular microscope. The zooplankton were identified using the standard study of Davis (1955), Kasturirangan (1963), Newell and Newell (1977), Smith (1977), Wimpenny (1966), Todd and Laverack (1991) and Perumal *et al.* (1998).

Data analysis: Concerning biodiversity, the number of species was estimated for each station and zooplankton abundance was used to compute heterogeneity according to the Shannon and Weaver (1949) index. Species richness was calculated using the following formula given by Simpson index formula (D) and Evenness (or) equality (J) in the distribution of individuals among the various species was calculated using the formula of evenness by Pielou (1966). Two way ANOVA test was employed to find out the variations in physico-chemical parameters, population density, species diversity, species richness and species evenness in relation to stations and seasons. Pearson-correlation coefficient analysis was performed between physico-chemical parameters and population density, species diversity, species richness and species evenness for both the stations.

RESULTS AND DISCUSSION

Environmental parameters: Total rainfall of 2026 mm was recorded from September 2006 to August 2007. Monthly rainfall (mm) varied from 15.75-746.75 during the study period. No rainfall was recorded during the months of January and March.

The maximum rainfall (746.75 mm) was recorded during the north east monsoon (November, 2006) and minimum (15.75) during the month of June, 2007 (Fig. 2). Rainfall is the most important cyclic phenomenon in tropical countries as it brings important changes in the hydrographical characteristics of the marine and estuarine environments. 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 or mostly stable inthe absence of rainfall. Maruthanayagam and Subramanian have also reported the occurrence of bulk of rainfall during northeast monsoon season along the southeast coast of India. The air and surface water temperature (°C) ranges were: 25.0-29.5; 24.0-28.5 at station 1 and 2, respectively. The minimum temperature was recorded during the monsoon season (December, 2006) and the maximum temperature during summer season May 2007 (Fig. 3 and 4). The surface water temperature showed an increasing trend from December to May. Generally, surface water temperature is influenced by the intensity of solar radiation, evaporation, fresh water influx and cooling and mix up with ebb and flow from adjoining neritic waters. The water temperature during December was low because of strong land sea breeze and precipitation and the recorded high summer value could be attributed to

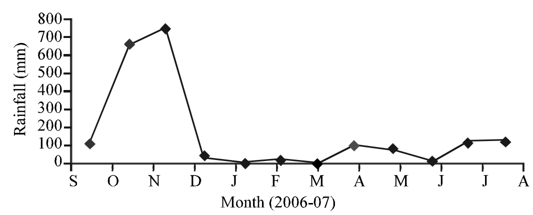

Fig. 2: Rainfall recorded during 2006-2007 in the study area

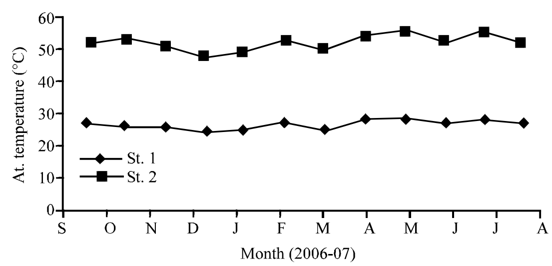

Fig. 3: Seasonal variation in atmospheric temperature during 2006-2007 at stations 1 and 2

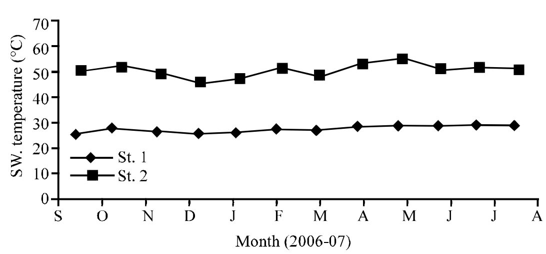

Fig. 4: Seasonal changes in surface water temperature during 2006-2007 at station 1 and 2

high solar radiation (Das *et al*., 1997; Govindasamy *et al*., 2000; 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 = 0.925 at station 1 and r = 0.914 at station 2) between air and surface water temperatures for both stations. The salinity (%) ranges for station 1 and 2 were 26-34 and 27-35, respectively.

The maximum salinity (34) was observed during the post-monsoon and summer seasons and the minimum salinity (26) during the monsoon season in station 1. The maximum salinity (35) was observed during the summer season and the minimum salinity (27) during the monsoon season in station 2. 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 faunal distribution of the coastal ecosystems (Chandra Mohan and Sreenivas, 1998).

Presently, wide salinity variations were observed between 2 stations and during different season (Fig. 5). Generally, changes in the salinity in the brackish water 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 presently evidenced by the positive correlation (r = -0.075 at station 1 and r = -0.009 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 recorded higher values could be attributed to the low amount of rainfall, higher rate of evaporation and also due to neritic water dominance as reported by earlier researchers in other areas (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, as reported by Mitra *et al.* (1990) in the bay of Bengal and coastal waters of Kalpakkam by Satpathy (1996). The pH of the water varied from 7.8-8.2 in station 1 and 7.9-8.3 in station 2. The maximum pH (8.2) was observed during the monsoon and summer seasons and the minimum pH (7.8) during the monsoon and post-monsoon seasons in station 1. The maximum pH (8.3) was observed during the summer season and the minimum pH (7.9) during the monsoon and post-monsoon seasons in station 2 (Fig. 6). Hydrogen ion concentration (pH) in surface waters remained alkaline throughout the study period at all the stations with maximum value during the monsoon season and the minimum during monsoon and post monsoon seasons (Fig. 6). Generally, fluctuations in pH values during different seasons of the year 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 besides decomposition of organic materials as stated by Rajasegar (2003). 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). Dissolved oxygen (mL^{-1} concentration varied from 3.77-5.24 in station 1 and 3.15- 5.03 in station 2. The minimum value was recorded during the summer season and the maximum values during monsoon season at the both stations (Fig. 7). It is well known that the temperature and salinity affect the

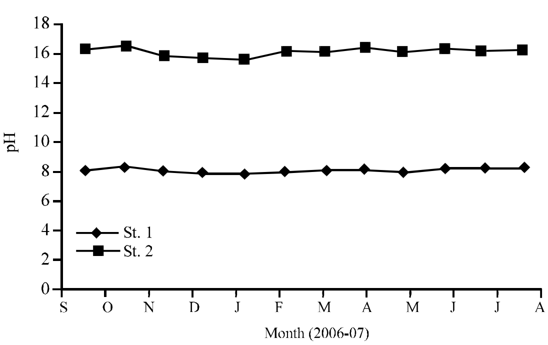

Fig. 6: Seasoinal changes in pH during 2006-2007 at station 1 and 2

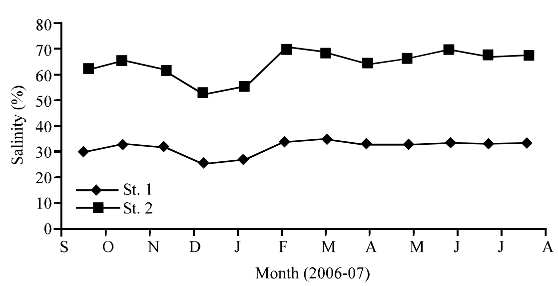

Fig. 5: Seasonal changes in salinity during 2006-2007 at station 1 and 2

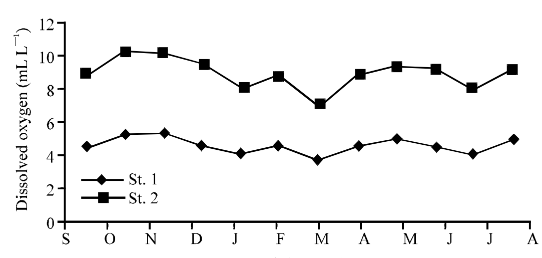

Fig. 7: Seasoinal changes in disolved oxygen during 2006-2007 at station 1 and 2

dissolution of oxygen (Vijayakumar *et al*., 2000). 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 (Mitra *et al*., 1990; Das *et al*., 1997). The concentration of inorganic nitrate ranged between 3.98 and 7.05 in station 1 and 3.54 and 6.93 in station 2. The maximum concentration was recorded during the monsoon season and minimum was recorded during the pre-monsoon season in all stations (Fig. 8).

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 nitrate value during monsoon season could be mainly due to the organic materials received from the catchment areas during ebb tide (Das *et al*., 1997). The increased nitrates level was due to fresh water inflow and terrestrial run-off during the monsoon season (Santhanam and Perumal, 2003). Another possible way of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite formation (Rajasekar, 2003). The recorded low values 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, 1996; Das *et al*., 1997; Govindasamy *et al*., 2000). The dissolved inorganic nitrite concentration (µM) values ranges for station 1 and 2 were 0.31-0.98 and 0.28-0.83, respectively. The minimum nitrite values were recorded during the post-monsoon in station 1 and monsoon in station 2 and the maximum values were recorded during pre-monsoon season at both the stations (Fig. 9). The recorded higher nitrite values during pre monsoon season could be due to the increased planktonic organisms 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) (Fig. 9). The recorded low nitrite value during monsoon season may be due to less freshwater inflow and high salinity (Murugan and Ayyakannu, 1991).

The recorded phosphate (µM) concentration ranges were: 0.42-2.82 and 0.26-1.95 at station 1 and 2, respectively. The minimum value was recorded during the monsoon season and the maximum during pre-monsoon season at both stations (Fig. 10). The recorded high concentration of inorganic phosphates during pre-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) (Fig. 10). Further, regeneration and release of total phosphorus from bottom mud into the water column by turbulence and mixing is also attributed to the recorded higher monsoonal values (Chandran, 1982). The recorded low monsoonal phosphate values could be attributed to the high utilization of phosphate by phytoplankton (Rajasegar, 2003). The variation may also be due to the processes like adsorption and desorption of phosphate and buffering

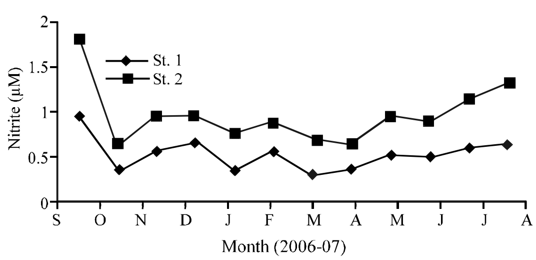

Fig. 8: Seasonal changes nitrite during 2006-2007 at station 1 and 2

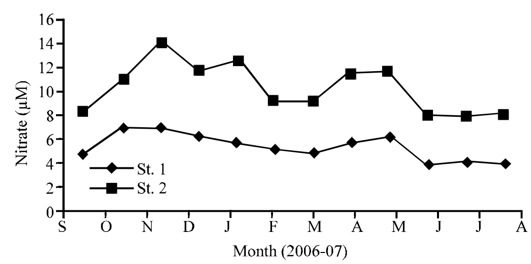

Fig. 9: Seasonal changes nitrite during 2006-2007 at station 1 and 2

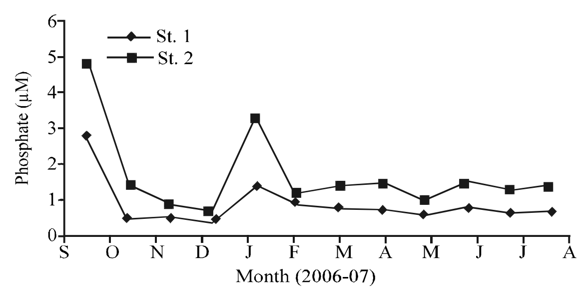

Fig. 10: Seasonal changes phosphate during 2006-2007 at station 1 and 2

action of sediment undervarying environmental conditions (Rajasegar, 2003). Moreover, the weatherings of rocks soluble alkali metal phosphate, the bulk of which are carried into the estuaries are also responsible for the recorded higher values (Gowda *et al*., 2001). The reactive silicate (μm) concentration ranges were: 19.96-50.11 and 25.96-53.32 at station 1 and 2, respectively. The minimum values were recorded during summer in station 1 and post-monsoon in station 2 and the maximum values were recorded during monsoon season at both stations (Fig. 11). The silicate content was higher than the other nutrients (NO_3, NO_2 and PO_4) and the recorded high monsoonal values may be due to heavy inflow of monsoonal freshwater derived from land drainage carrying silicate leached out from rocks. Further, due to the turbulent nature of water, the silicate from the bottom sediment might have been exchanged with overlying water (Govindasamy and Kannan, 1996; Rajasegar, 2003) (Fig. 12).

The dissolution of particulate silicon carried by the river, the removal of soluble silicates by adsorption and co-precipitation of soluble silicon with humic compounds and iron (Rajasegar, 2003) are some of the processes which might have caused the depletion of silicate during summer season. The recorded low summer values could also be attributed to uptake of silicates by phytoplankton for their biological activity (Mishra *et al*., 1993; Ramakrishnan *et al*., 1999). Ammonia concentration (μM) values ranges were: 0.016-0.85 and 0.018-0.83 at species density during 2006-2007 at station 1 and 2,

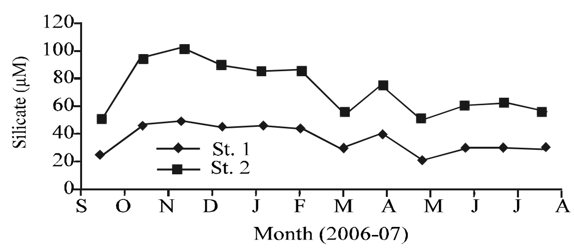

Fig. 11: Seasonal changes in silicate during 2006-2007 at station 1 and 2

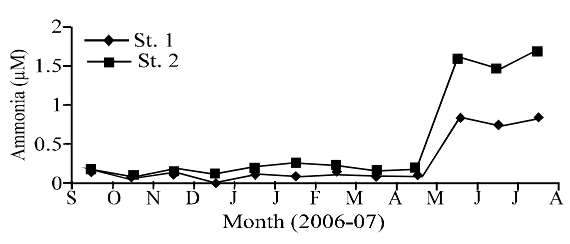

Fig. 12: Seasonal changes in ammonia during 2006-2007 at station 1 and 2

respectively. The maximum values were recorded during the pre-monsoon season and the minimum values during the monsoon season at station 1 and 2. Higher concentration of ammonia was observed during the pre-monsoon season in both the stations. Lower concentration of ammonia was observed during the monsoon season in both stations (Fig. 12).

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 as opined by Segar and Hariharan (1989).

Zooplankton species composition and community structure

Species composition: Zooplankton recorded during the study include the members of Foraminifera, Ciliata, Hydrozoa, Chaetognatha, Rotifera, Cladocera, Copepoda, Mysidacea, Amphipoda, Cumaceae, Decapoda, Salpida and Doliolida, Pteropoda besides Meroplankton. Species composition of zooplankton recorded at Sation 1 and 2. During the present investigation, a total of 121 zooplankton were recorded from all the 2 stations. At station 1, 88 species of zooplankton were recorded which include 3 species of foraminifera, 14 species of ciliata, 3 species of rotifera, 44 species of copepoda, 1 species of appendicularia, 2 species of decapoda, 2 species of chaetognatha, 1 species of salpida, 2 species of coelentrata, 1 species of pteropoda, besides 15 larvae.

At station 2, 114 species of zooplankton were identified which include 3 species of Foraminifera, 13 species of ciliata, 58 species of copepoda, 3 species of appendicularia, 1 species of salpida, 1 species of doliolida, 2 species of decapoda, 3 species of chaetognatha, 1 species of amphipoda, 1 species of cumacea, 5 species of coelentrata, 1 species of pteropoda, 2 species of cladocera and 20 forms of larvae.

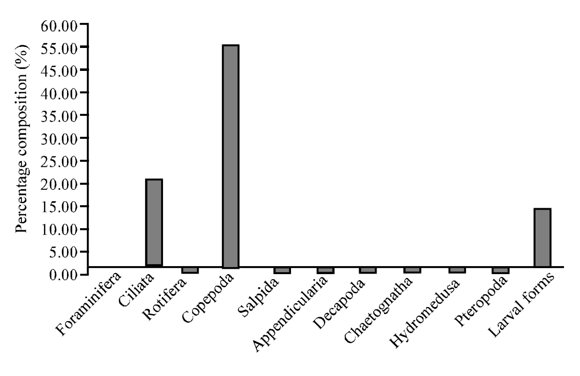

Fig. 13: Seasonal variation in zoooplankton group wise (%) composition during 2006-07 at station 1

Percentage composition: At station 1, copepoda formed the dominant group (55.76%) followed by ciliata (22.76%), larvae (16.63%), foraminifera (2.25), chaetognatha (0.82%), rotifera (0.59%), decapoda (0.49%), appendicularia (0.36%), pteropoda (0.10%), salpida (0.08%) and hydromedusa (0.07%) (Fig. 13). At station 2, Copepoda formed the dominant group (56.20%) followed by ciliata (21.29%), larvae (15.57%), foraminifera (2.29) appendicularia (1.54%), chaetognatha (0.82%), hydromedusa (0.73%), decapoda (0.60 %), pteropoda (0.31 %), cladocera (0.28%), salpida (0.19%) and doliolida (0.18 %) (Fig. 14).

Zooplankton recorded in the present study consisted of a total of 121 forms including larvae. The order of abundance of various groups of plankton are Copepoda>Larvae>Ciliata>Ichthyoplankton>Cladocera> Rotifera>Hydrozoa>Salpida and Doliolida>Amphipoda> Mysids larvae>Polychaete larvae>Cumacea>Decapoda> Chaetognatha>Pteropoda>Foraminifera. Abundance of various zooplankters in the coastal areas is being fluctuated in accordance with salinity regime. Among the various groups, copepods formed a predominant group with a total number of 59 species to which the calanoids contributed the bulk of copepods followed by cyclopoids and harpacticoids and the important recorded forms were: *Acartia* (*Acartia clausi*, *A. spinicauda*, *A. southwelli*, *A. erythraea*, *A. danae* and *A. centrura*) and *Oithona brevicornis*, *O. rigida*, *O. similes*, *O. spinirostris* and *O. linearis* (found in both the stations). Among, the harpacticoid copepods, *Euterpina acutifrons, Microsetella norvegica* and *Macrosetella gracilis* were present throughout the study period at both stations. Also, *Acrocalanus gibber*, *A. gracilis*, *Paracalanus parvus* and *A. spinicauda* were common forms found in both the stations which might be due to their ability to adapt to the prevailing environmental conditions and also due to the continuous breeding behaviour of the species.

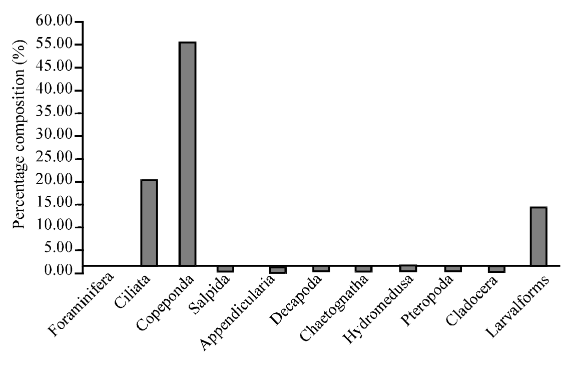

Fig. 14: Seasonal variation in zooplankton group wise (%) composition during 2006-07 at station 2

Similar opinion was earlier given by Neelam Ramaiah and Nair (1997), Sarkar *et al.* (1986) and Kowenberg (1993). Copepods were found to be numerically abundant throughout the study period at both the stations. Similar copepods abundance was also earlier recorded by Kumar (1991), Rajasegar (1998) and Santhanam (1998, 2002) from Vellar estuary, Jegadeesan (1986) and Edward (1988) from Coleroon estuary, Ambikadevi (1993) and Saraswathi (1993) from Arasalar and Kaveri estuaries, Ananthan (1994) from Pondicherry coast, Sastry and Chandramohan (1995) from Godavari estuary, Abidi *et al.* (1983) from Akarpati (Navapur) coast, Gajbhiye and Desai (1981) in polluted and unpolluted regions of Bombay waters, Padmavati and Goswami (1996) in Mandovi-Zuari estuarine system of Goa, Krishnakumari and Nair (1988) in Vashishti estuary, Anbhazhagan (1988) in Kodiakarai waters, Vijayakumar and Sarma (1988) from Visakapattinam harbour and Ambler *et al.* (1991) and Osore (1992) from Kenyan mangrove waters.

The abundance of this group steadily increased at all 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 important factors that controlled the distribution of copepods were rainfall and salinity as suggested by Bijoy Nandan and Abdul Azis (1994).

Tintinnids showed a wide range of salinity tolerance and the recorded high summer density might be due to the influence of neritic waters. These results are in agreement with the previous findings of Chandran (1982), Damodara Naidu *et al.* (1976) and Santhanam (1998) from Vellar estuary; Jegadeesan (1986) and Edward (1988) from Coleroon estuary. The meroplanktonic organisms such as bivalve veliger, gastropod veliger, copepod nauplii and cirriped nauplii were commonly available in Kodiakkarai coastal waters (Damotharan *et al.*, 2007).

The fish larvae were also found to be common in all the stations. It indicates that the coastal ecosystem serves as a breeding and nursery grounds for a variety of fish. These findings are line with the reports of Chandrasekaran and Natarajan (1993). The recorded higher zooplankton density during summer season might be due to the relatively stable environmental conditions which prevailed during this season and great neritic element presence from adjacent sea could have also contributed to the maximum density of zooplankton. Further, salinity is the key factor influencing zooplankton distribution and abundance (Padmavati and Goswami, 1996). Zooplankton population density was low during monsoon season due to the hydrographically washable environmental condition. The monsoonal flow causes great depletion of zooplankton population density. Padmavati and Goswami (1996) (Fig. 15) and Ananthan (1994) have stated that the heavy rain changed the salinity, temperature and other environmental variables which inturn decreased the zooplankton density.

Further, the higher population densities of zooplankton observed during summer were coincided with the peak of phytoplanktonic density.

The phytoplankton density showed positive correlation with zooplankton density. It is supported from the earlier observations of Govindasamy and Kannan (1991) and Godhantaraman (1994) from Pichavaram mangroves and Krishnamurthy *et al.* (1995) from Parangipattai and Pichavaram mangrove areas and Jegadeesan (1986) in Coleroon estuary and Murugan (1989) from Uppanar backwater.

Further, higher population density with more number of copepods species were also observed by Rajagopalan *et al.* (1992). Species diversity values ranges for station 1 and 2 were: 3.01-3.67 and 2.94-4.03, respectively.

The minimum species diversity was recorded during the monsoon season at both stations and the maximum species diversity recorded during post monsoon season at station 1 and summer season at station 2. Maximum species diversity of zooplankton was recorded during post monsoon season at station 1 and summer season at station 2 (Fig. 16). The high values of zooplankton species diversity were found to be associated with the high zooplankton density that also indicated the stable high salinity and phytoplankton density. It is supported by the positive correlation value obtained between diversity and density (r = 0.787 at station 1 and r = 0.669 at station 2).

The low species diversity was observed during monsoon season at both stations which could be attributed to heavy rainfall influx and low salinity. Godhandaraman (1994) and Rajkumar *et al.* (2004) have obtained similar values from Pichavaram mangroves. Species evenness values ranges for station 1 and 2 were 0.83-0.90 and 0.86-0.93, respectively. The minimum species evenness values were recorded during the monsoon season at both stations and the maximum values during the post-monsoon season at both stations. The maximum evenness value was recorded during post-monsoon and summer seasons and the minimum values during monsoon season (Fig. 17).

Similar type of high evenness values were recorded earlier by Rajasegar (1998) from Vellar estuary and from Uppanar estuary by Murugan (1989). Species richness ranges for station 1 and 2 were 0.93-0.97 and 0.93-0.98, respectively. The minimum species richness was recorded during monsoon season at both stations and the maximum recorded during the post monsoon season at both stations.

The maximum richness value was recorded during summer season and the minimum richness during post-monsoon and monsoon seasons (Fig. 18). As reported earlier by Rajasegar (1998) from Vellar estuary and from Uppanar estuary by Murugan (1989).

The statistical correlation values of evenness showed positive correlation with species richness and species diversity.

The results of Analysis of Variance (ANOVA) for the difference in zooplankton distribution between the stations are significant at 0.05% level.

The results of the present study showed that a combination of factors influence the zooplankton

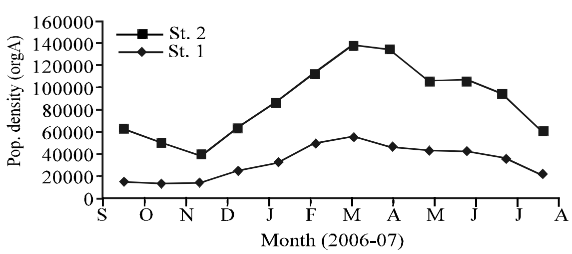

Fig. 15: Seasonal variation in zoooplankton population density during 2006-2007 at station 1 and 2

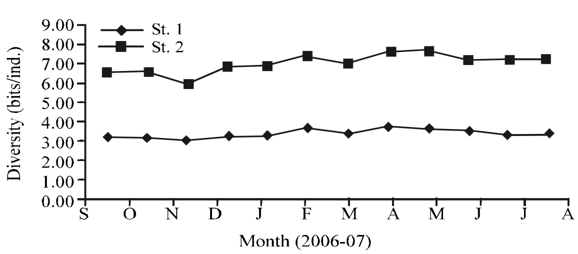

Fig. 16: Seasonal variation in zoooplankton species diversity during 2006-2007 at station 1 and 2

Fig. 17: Seasonal variation in zooplankton species evenness during 2006-2007 at station 1 and 2

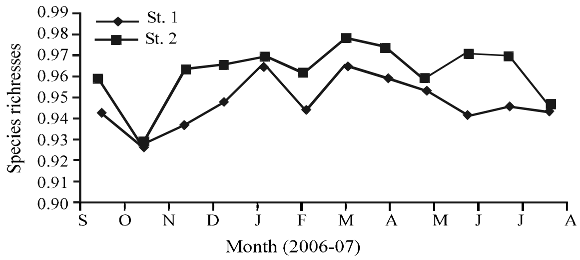

Fig. 18: Seasonal variation in zooplankton species richness during 2006-2007 at station 1 and 2

distribution and abundance in Kodiakkarai coastal waters. Among the various factors examined, abrupt change in salinity caused by rainfall can be considered as the most important water quality parameter which affects zooplankton abundance as reported previously by many researchers. The study has proved that Kodiakkarai costal waters are relatively unpolluted with rich zooplankton diversity. The present basic information of the zooplankton distribution and abundance would form a useful tool for further ecological assessment and monitoring of these coastal ecosystems of point calimere coastal waters.

CONCLUSION

The result of this study shows great differences between the assemblage and diversity of the zooplankton in these two parts of the point calimere coastal waters. Long-term studies are needed for ecological assessment and monitoring of these coastal ecosystems. The present investigation provides baseline data on zooplankton distribution and abundance and further.

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REFERENCES

Abidi, S.A.H., B.N. Desai and J. Ram, 1983. Studies on the hydrography and plankton off Akarapati near Navapur, west coast of India during February-March. Mahasagar. Bull. Natl. Inst. Oceanogr., 16: 91-94.

Aksornkoae, S., N. Paphavasit and G. Wattayakorn, 1993. Mangroves of Thailand: Present Status of Conservation, Use and Management. In: The Economic and Environmental Values of Mangrove Forests and their Present State of Conservation, Clough, B.F. (Ed.). ISME, Okinawa, Japan, pp: 83-133.

Ambikadevi, P., 1993. Studies on zooplankton in Arasalar and Kaveri estuaries, South east coast of India. Ph.D. Thesis, Annamalai University, India.

Ambler, J.W., F.D. Ferrari and J.A. Fornshell, 1991. Population structure and swarm formation of the cyclopoid copepod, *Dioithona oculata* near mangrove cays. J. Plankton Res., 13: 1257-1272.

Ananthan, G., 1994. Plankton ecology and heavy metal studies in the marine environs of Pondicherry, India. Ph.D. Thesis, Annamalai University, India.

Anbhazhagan, P., 1988. Hydrobiology and benthic ecology of kodiakkarai coastal sanctuary (Southeast coast of India). Ph.D. Thesis, Annamalai University, India.

Banse, K., 1995. Zooplankton: Pivotal role in the control of ocean production. Indian J. Mar. Sci., 52: 265-277.

Bhunia, M. and A. Choudhury, 1982. Some ecological consideration for zooplankton production in *Chemagari creek*, Sagar island (South), Sunderbans. Mahasagar-Bull. Natl. Inst. Oceanogr, 15: 247-252.

Bijoy Nandan, S. and P.K. Abdul Azis, 1994. Organic matter of sediments from the retting and the non-retting areas of Kadinamkulam estuary, Southeast coast of India. Indian J. Mar. Sci., 25: 25-28.

Boak, A.C. and R. Goulder, 1983. Bacterioplankton in the diet of calanoid copepod *Eurytemora* sp. in the humber estuary. Mar. Biol., 73: 139-149.

Butterfield, N.J., 2002. *Leanchoilia* guts and the interpretation of three dimensional structures in burgess shale-type fossil. Paleobiology, 28: 155-171.

Calbert, A., M.R. Landry and R.D. Scheinberg, 2000. Copepod grazing in a subtropical bay: Species-specific responses to a midsummer increase in nanoplankton standing stock. Mar. Ecol. Prog. Ser., 193: 75-84.

Chandra Mohan, P. and N. Sreeenivas, 1998. Diel variations in zooplankton populations in mangrove ecosystem at Gaderu canal, Southeast coast of India. Indian J. Mar. Sci., 27: 486-488.

Chandran, R., 1982. Hydrobiological studies in the gradient zone of the Vellar estuary. Ph.D. Thesis, Annamalai University, India.

Chandrasekaran, V.S. and R. Natarajan, 1993. Mullet seed resources of *Pichavaram mangrove*, Southeast coast of India. J. Mar. Biol. Assoc. India, 35: 167-174.

Choudhury, S.B. and R.C. Panigrahy, 1991. Seasonal distribution and behaviour of nutrients in the creek and coastal waters of Gopalpur, East coast of India. Mahasagar-Bull. Natl. Inst. Oceanogr., 24: 81-88.

Damodara Naidu, W., R. Santhanam, K. Krishnamurthy and R. Natarajan, 1976. The species biomass and seasonal composition of Tintinnida (Protozoa: Ciliata). Proceedings of the Symposium on Warm Water Zooplankton, Special Publication, (WWZ,76), UNESCO. NIO, Goa, India, pp: 520-527.

Damotharan, P., P. perumal, M. Rajkumar and N.V. Perumal, 2007. Meroplankton diversity in Kodiakkarai (Point Calimere) coastal waters (Southeast coast of India). Proceeding of the National Seminar on Emerging Scenario in Zoology, Sept. 27th, National College, Trichy, pp: 108-116.

Das, J., S.N. Das and R.K. Sahoo, 1997. Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, East coast of India. Ind. J. Mar. Sci., 26: 323-326.

Davis, C.C., 1955. The Marine and Freshwater Plankton. Michigan State University Press, Michigan, USA., pp: 562.

De Jonge, V.N., M. Elliot and E. Orive, 2002. Causes, historical development, effects and future challenges of a common environmental problem: Eutrophication. Hydrobiologia, 475-476: 1-19.

Dolan, J.R., 2000. Tintinnid ciliate diversity in the Mediterranean Sea: Longitudinal patterns related to water column structure in late spring-early summer. Aquatic Microbial. Ecol., 22: 69-78.

Dolan, J.R., H. Claustre, F. Carlotti, S. Plounevez and T. Moutin, 2002. Microzooplankton diversity: Relationships of tintinnid ciliates with resources, competitors and predators from the Atlantic coast of Morocco to the Eastern Mediterranean. Deep-Sea Res., 49: 1217-1232.

Edward, K.P., 1988. Studies on the ecology of *Coleroon estuary*, Southeast coast of India. Ph.D.Thesis, Annamalai University, India.

Gajbhiye, S.N. and B.N. Desai, 1981. Zooplankton variability in polluted and unpolluted waters of Bombay. Mahasagar, 14: 173-182.

Godhantaraman, N., 1994. Studied the delayed hydrobiological account of 35 species of rotifers belonging to 17 genera in *Pichavaram mangroves* (South India). Ciencias Marinas, 20: 371-391.

Gouda, R. and R. C. Panigrahy, 1996. Ecology of phytoplankton in coastal waters off Gopalpur, East coast of India. Indian J. Mar. Sci., 25: 81-84.

Govindasamy, C. and L. Kannan, 1991. Rotifers of the Pitchavaram mangroves (Southeast coast of India): A hydrobiological approach. Mahasagar–Bull. Natl. Inst. Oceanogr., 23: 55-62.

Govindasamy, C. and L. Kannan, 1996. Ecology of rotifers of *Pichavaram mangroves*, Southeast coast of India. Indian Hydrobiol., 1: 69-76.

Govindasamy, C., L. Kannan and J. Azariah, 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast. Indian J. Environ. Biol., 21: 1-7.

Gowda, G., T.R.C. Gupta, K.M. Rajesh, H. Gowda, C. Lingadhal and A.M. Ramesh, 2001. Seasonal distribution of phytoplankton in *Nethravathi estuary*, Mangalore. J. Mar. Biol. Ass. India, 43: 31-40.

Gowing, M.M. and K.F. Wishner, 1992. Feeding ecology of benthopelagic zooplankton on an Eastern tropical pacific seamount. Mar. Biol., 112: 451-467.

Guisande, C., J. Sanchez, I. Maneiro and A. Miranda, 1996. Trade off between offspring number and offspring size in the marine copepod *Euterpina acutifrons* at different food concentrations. Mar. Ecol.-Prog. Ser., 143: 37-44.

Gyllenberg, G., 1984. The role of bacteria in *Eurytemora* feeding behaviour. Crustaceana, 7: 229-232.

Ingolfsson, A. and E. Olafsson, 1997. Vital role of drift algae in the life history of the pelagic harpacticoid *Parathalestris croni* in the Northern North Atlantic. J. Plankton Res., 19: 15-27.

Jegadeesan, P., 1986. Studies on the environmental inventory of the marine zone of *Coleroon estuary* and inshore waters of pazhayaru, Southeast coast of India. Ph.D. Thesis, Annamalai University, India.

Jonsson, P.R. and P. Tiselius, 1990. Feeding behaviour, prey detection and capture efficiency of the copepod *Acartia tonsa* feeding on planktonic ciliates. Mar. Ecol. Prog. Ser., 60: 35-44.

Kasturirangan, L.R., 1963. A Key for the More Common Planktonic Copepods of the Indian Waters. CSIR Publication, New Delhi, pp: 87.

Kowenberg, J.H.M., 1993. Copepod distribution in relation to seasonal hydrographic and spatial structure in the North–Western Mediterranean (Gulf du Lion). Estuar. Coastal Shelf Sci., 38: 69-90.

Krishnakumari, L. and V.R. Nair, 1988. Biomass, organic carbon and calorific content of zooplankton from the Arabian sea off central West coast of India. Indian J. Mar. Sci., 17: 78-80.

Krishnamurthy, K., K. Kathiresan, L. Kannan, N. Godhantaraman and W.D. Naidu, 1995. Cyanobacteria: Plankton of Parangipettai (Porto Novo), India. Fascile No. 2. Annamalai University, Parangipettai, pp: 27.

Kumar, K., 1991. Studies on copepods occurring in coastal waters of Parangipettai. Ph.D. Thesis, Annamalai University, India.

Kurashov, E.A., 1996. Distribution and summer diapause of *Canthocamptus staphylinus* (Jurine) (Copepoda: Harpacticoida) in lake Ladoga. Hidrobiologia, 320: 191-196.

Marcus, N., 2004. An overview of the impacts of eutrophication and chemical pollutants on copepods of the coastal zone. Zool. Stud., 43: 211-217.

Mishra, S., D. Panda and R.C. Panigrahy, 1993. Physico-chemical characteristics of the bahuda estuary (*Orissa*), East coast of India. Ind. J. Mar. Sci., 22: 75-77.

Mitra, A., K.C. Patra and R.C. Panigrahy, 1990. Seasonal variations of some hydrographical parameters in tidal creek opening into the bay of Bangal. Mahasager Bull. Natl. Inst. Oceanogr., 23: 55-62.

Murugan, A. and K. Ayyakannu, 1991. Ecology of uppanar backwaters, cuddalore: 2. nutrients. Mahasagar- Bull. Natl. Inst. Oceanogr., 24: 103-108.

Murugan, A., 1989. Ecobiology of cuddalore-uppanar backwaters, Southeast coast of India. Ph.D. Thesis, Annamalai University, India.

Nair, N.B., P.K.A. Aziz, H.S. Narayanan, A. Arunachalam, K. Krishnakumar and K. Dharmaraj, 1984. Ecology of Indian estuaries X: Distribution of total phosphorus, total nitrogen and total potassium in the sediment of *Ashtamudi estuary*. Mahasagar Bull. Natl. Inst. Oceanogr., 17: 33-39.

Newell, G.E. and R.C. Newell, 1977. Marine Plankton: A Practical Guide. 5th Edn., Hutchinson and Co. Ltd., London, pp: 244.

Ohtsuka, S., Y. Fukuura and A. Go, 1987. Description of a new species of *Tortanus* (Copepoda: Calanoida) from Kuchinoerabu island, kyushu (Japan), with notes on its possible feeding mechanism and in-situ feeding habits. Bull. Plankton. Soc. Japan, 34: 53-64.

Osore, M.K.W., 1992. A note on the zooplankton distribution and diversity in a tropical mangrove creek system, Gazi, Kenya. Hydrobiologia, 247: 119-120.

Padmavati, G. and C. Goswami, 1996. Zooplankton ecology in the Mandovi-Zuari estuarine system of Goa, westcoast of India. Indian J. Mar. Sci., 25: 268-273.

Perumal, P., 1993. The influence of meteorological phenomena on the ecosystems of a tropical region, Southeast coast of India. A case study. Ciencias Marinas, 19: 343-351.

Perumal, P., P. Sampathkumar and P. Santhanam, 1998. Zoopalnkton of Parangipettai coatal waters. Monogr Series, Vol. I. UGC-SAP, CAS in Marine Biology, Annamalai University, Parangipettai, pp: 31.

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. J. Theoretical Biol., 13: 131-144.

Pierce, R.W. and J.T. Turner, 1992. Ecology of planktonic ciliates in marine food webs. Rev. Aqua. Sci., 6: 139-181.

Rajagopalan, M.S., P.A. Thomas, K.J. Mathew, T.S. Naomi, P. Kaladharan, V.K. Balachandran and G. Antony, 1992. Productivity of the Arabian sea along the Southwest coast of India. Bull. Cent. Mar. Fish. Res. Inst., 45: 9-37.

Rajasegar, M., 1998. Environmental inventory on Vellar estuary (Southeast coast of India) in relation to shrimp farming. Ph.D. Thesis, Annamalai University, India.

Rajasegar, M., 2003. Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. J. Environ. Biol., 24: 95-101.

Rajkumar, M., 2003. Hydrobiological studies in pitchavaram mangroves (Southeast coast of India) with references to plankton. M.Phil Thesis, Annamalai University, India.

Rajkumar, M., 2006. Studies on ecology, experimental biology and live feed suitability of copepods, *Acartia erythraea* giesbrecht and *Oithona brevicornis* giesbrecht from coleroon estuary (India). Ph.D. Thesis, Annamalai University, India.

Rajkumar, M., P. Santhanam and P. Perumal, 2004. Laboratory culture of calanoid copepod, *Acartia clausi* Giesbrecht. Appl. Fish Aqua., 4: 5-8.

Ramachandran, S., D.A. Ramesh and V.S. Gowri, 2000. Coastal ecosystems: Their problems and management. In: Management of Problems in Coastal Area Ocean Engineering Center, pp: 170-185.

Ramakrishnan, R., P. Perumal and P. Santhanam, 1999. Spatio-temporal variations of hydrographical features in the *Pichavaram mangroves* and *Mohi aqua* farm, Southeast coast of India. Proceeding of the International Seminar Applied Hydrogeochem, (ISAH'99), Published by Dept. of Geology, Annamalai University, Chidambaram, pp: 197-203.

Reddi, K.R., N. Jayaraju, I. Suriyakumar and K. Sreenivas, 1993. Tidal fluctuation in relation to certain physico-chemical parameters in Swarnamukhi river estuary, East coast of India. Indian J. Mar. Sci., 22: 232-234.

Reid, P.C., C.M. Turley and P.H. Burkill, 1991. Protozoa and their Role in Marine Processes. Springer-Verlag, Heidelberg.

Sampathkumar, P., 1992. Investigation on plankton in relation to hydrobiology and heavy metals in the Tranquebar-Nagapattinam coast, India. Ph.D. Thesis, Annamalai University, India.

Santhanam, P. and P. Perumal, 2003. Diversity of zooplankton in Parangipettai coastal waters, Southeast Coast of India. J. Mar. Biol. Assoc. India, 45: 144-151.

Santhanam, P., 1998. Studies on the ecology and culture of zooplankton from the vellar estuary and Bay of Bengal. M.Phil. Thesis, Annamalai University, India.

Santhanam, P., 2002. Studies on the ecology, experimental biology and live-food suitability of copepod, *Oithona rigida* giesbrecht from parangipettai coastal environments India. Ph.D. Thesis, Annamalai University.

Saraswathi, R., 1993. Hydrobiology of two estuarine systems (Arasalar and Kaveri) of the Southeast Coast of India with special reference to plankton. Ph.D. Thesis. Annamalai University, India.

Sarkar, S.K., B.N. Sing and R. Choudhury, 1986. Seasonal distribution of copepods in the *Hooghly estuary*, Northern bay of Bengal. Indian J. Mar. Sci., 15: 177-180.

Sastry, A.G.R.S. and P. Chandramohan, 1995. Zooplankton of vasishta *Godavari estuary*, a pre-pollution status survey. J. Mar. Biol. Ass. India, 37: 249-258.

Satpathy, K.K., 1996. Seasonal distribution of nutrients in the coastal waters of Kalpakkam, East coast of India. Indian J. Mar. Sci., 25: 221-224.

Segar, K. and V. Hariharan, 1989. Seasonal distribution of nitrate, nitrite, ammonia and plankton in effluent discharge area of Mangalore, West coast of India. Indian J. Mar. Sci., 18: 170-173.

Shannon, C.E. and W. Weaver, 1949. The Mathematical Theory of Communication. 1st Edn., University of Illinois Press, Urbana, IL., ISBN-10: 0252725484.

Siaz, E. and T. Kiorboe, 1995. Predatory and suspension feeding of the copepod *Acartia tonsa* in turbulent environments. Mar. Ecol. Prog. Ser., 122: 147-158.

Smith, D.L., 1977. A Guide to Marine Coastal Plankton and Marine Invertebrate Larvae. Kendal/Hunt Publishing Company, USA., pp: 161.

Steinberg, D.K., C.H. Pilskaln and M.W. Silver, 1998. Contribution of zooplankton associated with detritus to sediment trap swimmer carbon in Monterey Bay, California, USA. Mar. Ecol. Prog. Ser., 164: 157-166.

Stottrup, J.G., 2000. The elusive copepods: Their production and suitability in marine quaculture. Aquac. Res., 31: 703-711.

Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Hand Book of Seawater Analyses. 2nd Edn., Fisheries Research Board of Canada, Canada, pp: 310.

Subramanian, B. and A. Mahadevan, 1999. Seasonal and diurnal variations of hydro biological characters of coastal waters of Chennai (Madras) Bay of Bengal. Indian J. Mar. Sci., 28: 429-433.

Todd, C.D. and M.S. Laverack, 1991. Coastal Marine Zooplankton –A Practical Manual for Students. Cambridge University Press, Cambridge, ISBN-10: 0521409187.

Tokioka, T. and R. Bieri, 1966. Juveniles of *Macrosetella gracilis* (Dana) from clumps of *Trichodesmium* in the vicinity of Seto. Publ. Seto Mar. Biol. Lab. Kyoto Univ., 14: 177-184.

Turner, J.T. and J.C. Roff, 1993. Trophic levels and tropho species in marine plankton: Lessons from the microbial food web. Mar. Microbial Food Webs, 7: 225-248.

Uthoff, D., 1996. From traditional use to total destruction forms and extent of economic utilization in the Southeast Asian mangroves. Nat. Resour. Dev., 43-44: 58-97.

Uye, S. and Y. Rayano, 1994. Predatory feeding behaviour of *Tortanus* (Copepoda: Calanoida): life-stage differences and the predation impact on small planktonic crustaceans. J. Crustacean Biol., 14: 473-483.

Vannier, J., P.R. Racheboeuf, E.D. Brussa, M. Williams, A.W.A. Rushton, T. Servais and D.J. Siveter, 2003. Cosmopolitan arthropod zooplankton in the Ordovician seas. Palaeogeograp. Palaeoclimatol. Palaeoecol., 195: 173-191.

Verity, P.G. and V. Smetacek, 1996. Organism life cycles, predation and the structure of marine pelagic ecosystems. Mar. Ecol. Prog. Ser., 130: 277-293.

Vijayakumar, G.S. and V.V. Sarma, 1988. Zooplankton studies in *Visakhapatinam harbour* and near shore waters, East coast of India. Indian J. Mar. Sci., 17: 75-77.

Vijayakumar, S., K.M. Rajan, R.M. Mendon and V. Hariharan, 2000. Seasonal distribution and behaviuor of nutrients with reference to tidal rhythm in the Mulki estuary, Southwest coast of India. J. Mar. Boil. Ass. India, 42: 21-23.

Watanabe, T., C. Kitajima and S. Fujita, 1983. Nutritional values of live organisms used in Japan for mass propagation of fish: A review. Aquaculture, 34: 115-143.

Webber, M.K. and J.C. Roff, 1995. Annual structure of the copepod community and its associated pelagic environment off Discovery Bay, Jamaica. Mar. Biol., 123: 467-479.

Wimpenny, R.S., 1966. The Plankton of the Sea. Faber and Faber Limited, London, pp: 426.