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Deterioration in the Biodiversity of Copepods in Sewage Laiden Creeks of Mumbai Coast, West Coast of India: a Statistical Approach

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ABSTRACT

The coastal waters of Mumbai is known to receive copious amount of waste from the adjacent creeks and bays. Effluents from various industries including nuclear and thermal power stations are discharged into the Mumbai harbour- Thane creek confluence. The water quality has been reported to be deteriorating which may have adverse effect on the fauna especially zooplankton - the subtle community. Copepods contribute about 70-90% of the total zooplankton in the marine ecosystems. Major portion of the waste generated in the city is discharged into the Arabian Sea through creeks creating pockets of localized pollution. The Mumbai harbour – Thane creek system receives more than 180 million liters per day (mLd) of industrial waste. The projected daily domestic waste water flow for greater Mumbai for 1985 and 2005 are respectively 1350 and 2000 mLd. Water samples and zooplankton were collected from two creeks namely Bassein and Thane and also in Versova and Mahim, two stations along the coastal region. Nutrients were high during pre-monsoon. $PO_{4,}$ 42.0 µ at.l^{-1} and $NO_{3,}$ 43.0 µ at.l^{-1} being the highest values recorded. The suspended load in the creeks were high namely 87.5 mg.l^{-1} during pre-monsoon and 121 mg. l^{-1} during post-monsoon. At Bassein creek the zooplankton density ranged from 74 to 21435 no.$(100m^3)^{-1}$ and copepods, from 9 to 15698 no.$(100m^3)^{-1}$. At Thane zooplankton population was high and ranged between 228 and 69259 no.$(100m^3)^{-1}$ and copepods from 7 to 57484 no.$(100m^3)^{-1}$. In a study made a decade earlier, 68 species were observed in Versova- Mahim environment and 49 species in the Thane creek. In the coastal stations, nutrients and suspended load were comparatively low and ammonia relatively high. The upper reaches of the creeks sustained high nutrients and suspended load and low density of zooplankton and in some stations' upstream, the percentage of copepods was very low where other zooplankton dominated. Rare and abundant species' clusters were formed separately highlighting the significance of the environment on the copepod distribution in the two creeks. The biological parameters along with water quality could uniquely discriminate the two creeks and also the coastal stations in the Versova and Mahim more precisely during postmonsoon season than premonsoon season.

Species diversity was high in the coastal stations away from the mouth of the creeks and was composed of estuarine, neritic and oceanic species. In the Bassein creek suspended load, DO and phosphate during pre monsoon, with DO replaced with salinity during post monsoon contributed to the total zooplankton abundance. Temperature, Salinity and Phosphate played a significant role during premonsoon season whereas temperature, pH and suspended load contributed to the abundance of zooplankton during postmonsoon ($P<0.05$, V.E.>82.13%) season in the Thane creek. This study showed a marked decrease in density and total number of species recorded from the localities. The reduction in diversity is more pronounced in the upstream stations where low dissolved oxygen (DO) and heavy concentrations of nitrates, ammonia and phosphates was observed. The hydrographical features point to habitat degradation due to waste input, both anthropogenic and industrial.

Key words: copepods; reduction; biodiversity; creek; degradation.

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INTRODUCTION

The effluent discharge from the metropolitan cities and industrial towns is a threat to the Indian coast during the past few decades, since it gives rise to severe environmental problems which lead to water quality deterioration. Certain published reports show that in many countries the failure of fishery could be attributed to the reduced zooplankton population especially the copepods. (Stottrup, 2000). Success of aquaculture of fin and shell fishes depend upon the availability of live-feed organisms like copepods. The health of coastal ecosystems could be assessed from the studies on zooplankton communities, especially copepods (Ramaiah and Nair, 1997). Most of the planktonic organisms are restricted in the neritic zone with high phytoplankton production due to the availability of nutrients, light and favourable physico-chemical variables. Evaluation of biological components such as species diversity, richness, evenness and dominance in the ecosystem is essential to understand detrimental changes in environs (Krishnamoorthy and Subramanian, 1999; Ashok Prabu et al., 2005). Species composition and seasonal variation in zooplankton abundance has been studied in other regions of Indian coastal waters (Gopinathan et al., 2001; Ashok Prabu et al., 2005; Mathivanan et al., 2007). Phytoplankton initiates the marine food chain, by serving as food to primary consumers like zooplankton, shellfish and finfish (Saravanakumar et al., 2008). Since, zooplankton are at the secondary trophic level of the marine ecosystems, analysing their properties and the relationships between them will allow us to detect and avoid a potential crash in the ecosystem (Conway, 2005). Copepods being the main secondary producers of marine pelagic environment rank also as important grazers. Both nauplius and adult stages are key components in food webs in rich productive estuaries and coastal regions. The domestic and chemical effluents are discharged into these waters especially in highly urbanized and industrial areas. Addition of nutrients derived from agricultural fertilizers, leaching of pesticides and other pollutants are most pronounced due to urbanization and industrial plants. Hydrographical properties of coastal systems are complex and are constantly altered by physical as well as anthropogenic disturbances. Discharge of untreated industrial effluents and sewage has augmented detrimental changes in estuaries, creeks and embayment, causing deterioration of water quality, loss of habitat and biodiversity, resulting in over all ecological degradation. The composition, abundance and diversity of copepods in Makupa creek, Mombasa which was subjected to dumping of domestic and industrial waste until recently is discussed in Osore, (1999). The difference in abundance and distribution of copepods in relation to pollution in two estuaries of the Basque coast was addressed by Uriate and Villate (2005). Minutoli et al (2002) highlighted the use of biomarkers in zooplankton for assessing the health status of marine and brackish environments. The Mumbai-harbour- Thane creek system receives more than 180 million liters per day (mld^{-1}) of industrial waste. The projected daily domestic waste water flow for greater Mumbai for 1985 and 2005 are respectively 1350 and 2000 mld^{-1}. To assess the changes in the biota water samples and zooplankton were collected from two creeks namely Bassein and Thane and also in Versova and Mahim, two stations along the coastal region. Copepods were studied during premonsoon and postmonsoon along with relevant environmental data. The water quality studies of Mumbai area was studied by Zingde et al (1989). Reports on copepods of polluted environments of Mumbai are limited to Gajbhiye (1982) and Gajbhiye et al (1991) as well as Ramaiah and Nair (1997). Stephen (1992, 2000) had given a general outline of the dominant copepods along the west coast of India.

Response of copepods to ecological changes have been reported from various geographical locations (Lindo, 1991; Mallin, 1991; Buskey, 1993; Kouwenberg 1994). However reports on stress induced variations in copepod community for Indian coastal waters are limited (Gajbhiye et al.,1991; Ramaiah and Nair, 1997). The coastal waters of Mumbai are known to receive copious amount of waste from the adjacent creeks and bays. Effluents from fertilizers, petrochemical, automobile , pharmaceutical, leather ,food and chemical industries and nuclear and thermal power stations are discharged into the Mumbai harbour – Thane creek – Bassein creek confluence (Zingde et al, 1989). The water quality has been reported to be deteriorating due to waste discharge, which may have adverse effect on the fauna. Previous reports on copepods of Mumbai harbour –Thane creek - Bassein creek (Ramaiah and Nair, 1997 and Nair and Ramaiah, 1998) showed reduction in the copepods species in this system probably because of environmental stress. Nair et al. (1999) studied the trophic structure and the levels of selected metals in the zooplankton community of Thane - Bassein creek Mumbai. The present study envisages a detailed account of the environmental effect on the copepods as well as total mesozooplankton abundance from the polluted creek environments of Mumbai to evaluate the seasonal changes if any over the year.

AREA OF STUDY

Mumbai is the largest metropolitan city in the west coast of India and is located at 18 º 55’N latitude and 72 º 50‘E longitude (Fig.1). The Arabian Sea traverses the entire length of the city on the western side. Along the eastern side it is separated from the main land of Konkan by Thane creek - Mumbai harbour. Thane creek forms the upper reaches of the harbour and extends about 26 km from the east port limit to the Arabian sea and is connected to the Ulhas river and Bassein creek at its northern extremity. The Ulhas river is very effective in flushing out the inlets and drains. The Thane creek joins the Arabian Sea at north of Dongri. The stations in the Thane creek are marked BYA to BYE from mouth to upstream and the stations in harbour and out in coastal region are indicated as BY1 to BY5. The creek opens at its south western approach to the Arabian Sea and is connected to the Bassein creek at its northern extremity. The Bassein creek joins the Arabian Sea at the northern end and the stations are shown as BSA to BSE from mouth to upstream and towards the sea as BS1 to BS5.The interior part of this complex creek system is fringed by rich mangrove vegetation and the land around is used for the cultivation and as salt pans . Dharamtar creek, the lower reaches of Amba river opens into the southern limits of the Mumbai harbour.

In Mumbai, temperature sharply increases from minimum value in January (av. 16.7 ºC) to maximum in May (av. 33.2ºC). Relative humidity is high during monsoon (79.6 %) and low during November and March. Rainfall is maximum during July – August and average rainfall amounts to 180 cm per year.

The tides in this area are of mixed type and are predominantly semidiurnal. The mean height of the spring tide is 3.7 m. During flood tide the movement of current is towards the north – east and during ebb tide towards south –west. Currents within the Thane - Bassein system are almost entirely due to the tidal ebb and flood flows. A tidal exchange flow between Thane creek and /Bassein creek is possible and during the flood tide the water may flow from the Thane creek to Bassein creek depending on the relative levels of high water in the interior part of the Thane creek (Zingde et al., 1979).

Major portion of the waste generated by the city is being discharged untreated into the creek environments creating pockets of localized pollution along the coast of Mumbai. The Mumbai harbour Thane creek system receives more than 180 million litres per day (mLd) of industrial waste waters (NIO, 1978). The projected daily domestic waste water flow for Greater Mumbai for 1985 and 2005 are respectively 1350 and 2000 mLd (NIO, 1978). The Bassein creek receives about 35 mLd of industrial effluent and 10 mLd of sewage through Ulhas river and Mumbai creek .

The coastal waters of Mumbai off Bassein does not reveal any gross impact of fluxes of pollutants transported through Bassein creek (NIO , 1997). However, the Bassein creek and Ulhas river receive a variety of wastes from a large number of industries and hence the area exhibits low DO and high concentration of nutrients, which increased towards the interior segment. The microbial populations indicate elevated levels of pathogens.

A marked decrease in DO along the length of Thane creek during dry season is due to input of organic load exceeding the assimilation capacity of the receiving water. Wide and irregular variations in DO and high and variable concentrations of nutrients are indicative of the pollution stress. The fluxes of toxic metals entering the bay are rapidly absorbed into the particulate matter and deposited on the bed, enriching the sediment. Levels of potential pathogenic bacteria in the Thane creek are abnormally high especially during the ebb indicating severe contamination of water and sediment (NIO, 1997).

Versova creek (19 º 01’.1’’ lat. and 72 º 48’long.) and Mahim by creek (19 º 01’.1’’ lat and 72 º 48’ long) are located along the coast between Bassein and Back Bay (Fig.1). and are shown as BYV and BYM which also receives voluminous domestic waste water which exert considerable environmental strain with low and variable DO, high nutrients and probability of active denitrification (NIO, 1997). Pathogenic bacteria in water and sediment are very high in these creek environments also, due to the influence of domestic waste water discharges.

MATERIALS AND METHODS

Location and Sampling methodology

Two series of sampling were done from 21 locations from Mumbai harbour, Thane creek, Bassein creek, Mahim creek and Versova creek during pre monsoon and post monsoon periods (February and May 1995; and November and December 1996).

Samples for water quality and zooplankton were collected from 10 stations in Bassein creek, 9 stations from Thane and one station each from Versova and Mahim creeks. Zooplankton collections were made with a Heron- Tranter Net (1973) having a mouth area of 0.25m^2 and mesh size of 0.33mm. The volume of water filtered was calculated with the TSK flowmeter fitted to the net. Oblique hauls of 6 minutes duration were taken. The flow meter reading was used to calculate the volume of water filtered. Observations were made during premonsoon and postmonsoon seasons. Duplicate samples were collected from each of the locations and average value was considered for evaluation. During 1985, a decade early, copepod samples were available from Versova and Mahim stations only.

water samples were collected from surface using a clean polyethylene bucket. Sub-surface water samples were collected using a plastic Niskin sampler with a mechanism for closing at a desired depth. The physico-chemical parameters considered for assessing the water quality were temperature, pH, salinity, suspended solids, dissolved oxygen, phosphate, nitrite, nitrate and ammonia. Water samples for the above parameters were analyzed as per standard methods of Strickland and Parsons (1972). Calorimetric measurement on water samples were made in a spectrophotometer (make: Shimadzu UV 160). Temperature of water samples was measured by a good quality centigrade thermometer immediately after collection. pH was measured on a digital pH meter (ECIL make no. 5652) after standardizing with standard buffers of pH 4,7 and 9 just before the use. The estimation of salinity was carried out in the laboratory by Argentometric method. For suspended solids known quantity of water was filtered through a pre weighed 0.45µm Millipore membrane filter paper, dried and weighed again to obtain the weight of particles retained by the filter paper. Dissolved Oxygen (DO) was determined by Wrinkler method. Phosphate, Nitrite, Nitrate and Ammonia were estimated using the methods given in Grasshoff (1972).

Zooplankton sampling and analysis were done following the standard method (UNESCO, 1968; IOBC, 1969). Samples were preserved in 5% buffered formalin. Copepods were sorted out from adequate subsamples depending on the size of the zooplankton sample, using a stempel pipette. Identification was made following the works of Giesbrecht (1892), Sewell (1947,1948), Kasturirangan (1963), Wallershaus (1969) and Bradford (1994). The counts of total copepods and various species were estimated for the entire sample and expressed as no/100m^3 for all the samples. Bray Curtis similarity index (Stephenson, 1974) was applied to group the species. Margalef richness index (Margalef, 1957), Shannon weiner diversity index (Shannon and weaver, 1963), Pielou's dominance index (Pielou, 1975; 1971) and Heip's evenness index (Heip, 1974) were used to define the community structure of the copepod species.

The abundance of a species can be related to the environmental parameters by means of a linear regression. But this relation gives only the prediction efficiency of a single factor at a time. In ecosystems, a number of factors are jointly controlling the bioactivities at a point of time or space. Therefore it is very essential that all the quantifiable parameters are to be considered simultaneously to have the best predictive model. Hence it is attempted to include the individual parameters viz., temperature, salinity, DO, PO_4, NO_2, NO_3, NH_4-N and suspended solids and their first order interaction effects in the prediction model (Sokal and Rholf, 1981, Jayalakshmy, 1998). Hence a Step up multiple regression analysis (Sokal and Rholf, 1981; Jayalakshmy,1998) was carried out to determine the most important ecological parameters which control/limit the distribution of the mesozooplankton/copepod species. The best predictive model is selected using variability explained (Snedecor and Cochran, 1967).

For the study of multivariate dependence structures, factor analysis was used for explaining the covariance of the responses. A bioethological space was developed through Q-mode and R-mode factor analysis (Morrison, 1978). The species groups which provide with the maximum information, called differential group, are determined for each area. The differential groups are similar to the major clusters in the dendrogram. The species density and dendrogram are presented side by side in Figs. (3-6) during premonsoon and post monsoon at Bassein creek and Thane creek. To substantiate the strict difference between Bassein and Thane creek, and the coastal stations in Versova and Mahim, Canonical Discriminant Analysis (CDA) was applied using the biological and physico-chemical parameters for premonsoon (Fig.7) and postmonsoon seasons separately (Fig.8).

RESULTS

Water quality parameters

Knowledge on the physic-chemical characteristics of an aquatic environment is of great significance for proper understanding of distribution, growth and physiological function of the biotic community inhabiting the area. Growth and proliferation of plankton are dependent on a variety of environmental factors which can either support or bring down their production capacity. Because of their short life cycle plankton responds quickly to environmental changes. The environmental variables affecting the stability of plankton population are many and importance of each parameter differs among between oceanic, near shore, estuarine and highly saline habitats.

Bassein creek

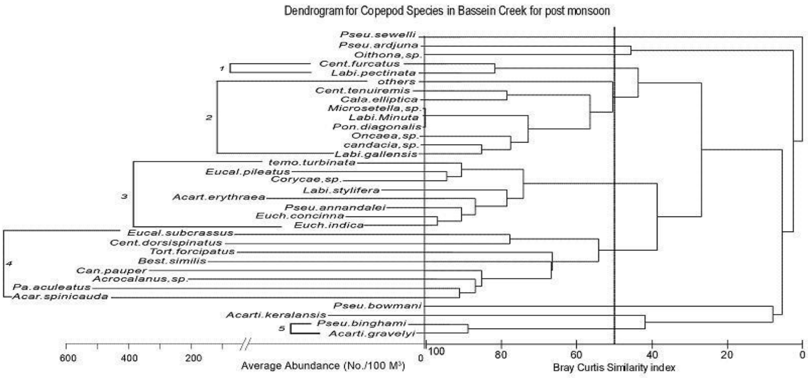
Dendrogram for Copepod Species in Bassein Creek for post monsoon

Figure 4

During premonsoon and postmonsoon periods (Fig. 2a), in general high temperature was noticed in the outer most and inner most stations. The lowest salinity during premonsoon being recorded from the most interior stations towards upstream. Highest value in the postmonsoon period was observed at the station BS4 and lowest at the upstream station. The pH variation was from 7.2 to 8.2 during both seasons, thus showing only marginal fluctuation between seasons. The DO level value during post monsoon were higher compared to premonsoon at all stations. Suspended load were high during premonsoon ranging from 13.9 to 87.0 mg.l^{-1} and most of the stations sustained > 30.0 mg.l^{-1}. In postmonsoon values were low ranging between 21.0 and 29.0 mg.l^{-1} except for stations BSA and BSB where the recorded values were 121.0 and 49.0 mg.l^{-1} respectively.

The phosphate values were high during premonsoon compared to postmonsoon. Levels of nitrate fluctuated within high ranges during both the seasons. Nitrite also showed a wide range from nondetectable levels (BSE) to 19.7 µg at. l^{-1} (BSD) during premonsoon. Post monsoon showed much higher values compared to premonsoon especially in the interior stations, the values during this season ranged between 0.1 and 9.4 µg at.l^{-1}. Ammonia concentration showed a wide range during premonsoon, nearly 4 times higher range than during postmonsoon. Standardised values (Fig. 2a) of the parameters were plotted for comparing distribution pattern between parameters in the two seasons in Bassein creek.

Thane creek

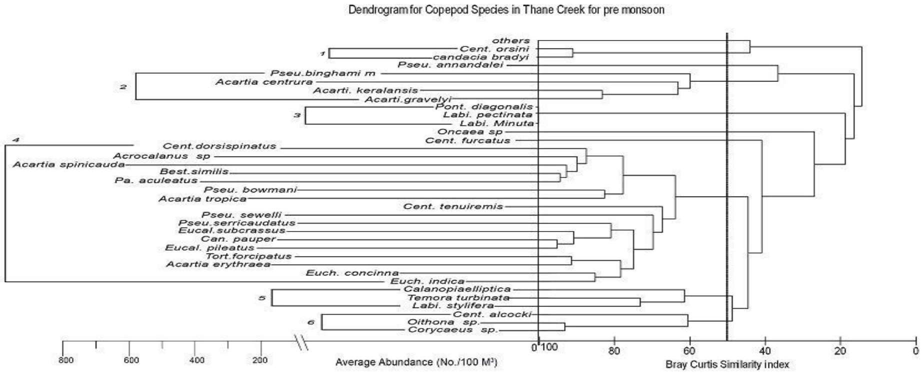

Figure 5

Temperature during premonsoon was nearly more by 4 units in the minimum and maximum values compared to post monsoon in this creek, ranging between 30 and 32.2 º C during premonsoon. The lowest salinity was noticed in the innermost station (BYE) and the highest salinity at BYA during premonsoon . In the post monsoon season salinity in the inner most stations dropped to 10.2 (BYE) and 26.4 PSU (BYD) with maximum at BY2. During premonsoon, pH fluctuated between 7.5 and 8.1 whereas during post monsoon most of the values were 7.8 with the lowest value of 7.3 at BYD. The DO value in this area varied over a marginally wider range during the hot season compared to off cold season, the post monsoon period. The lowest value of suspended load during premonsoon was more by 5 units while maintained the same highest (89.0 mg/l) value as during the post monsoon.

The phosphate value during the study period showed a wide range of 1.4 (BY5) to 4.2 µg at.l^{-1} l (BYD) during pre monsoon whereas the post monsoon values were low ranging from 1.6 to 6.6 except for an abnormal value of 15.2 µg at.l^{-1} at BYD. The lowest value during the pre monsoon for nitrate were higher by 3 times while the maximum value was same during both the seasons. The nitrite values in most of the stations during pre monsoon ranged from 0.1 to 12.4 µg at.l^{-1}. The post monsoon values showed a range of 0.4 to 9.0 µg at.l^{-1}. Ammonia concentration during pre monsoon varied over a lower range compared to the post monsoon values (Fig.2b).

Versova and mahim creek

The highest and lowest temperature did not show much variation between these stations during both seasons, the values ~31.8ºC during pre monsoon and 25.1ºC during post monsoon at Versova and Mahim .

The salinity values were relatively low at Versova creek during both seasons, the values being 28.7 and 30.8 PSU respectively for postmonsoon and pre monsoon periods . At Mahim creek, salinity in the respective order were 35.9 and 32.8 PSU. The pH of both the stations were 7.0 and 7.7 during premonsoon and 7.5 & 7.4 during post monsoon. The DO was very low (1.2 mg.l^{-1}) in the Versova creek during pre monsoon and high during post monsoon (6.1 mg.l^{-1}) whereas in the Mahim creek the respective values were moderate (4.1 and 3.1 mg.l^{-1}) for the two seasons. Versova creek showed comparatively high suspended load during pre monsoon (52.0 mg.l^{-1}) whereas during post monsoon it was 32.0 mg.l^{-1}. In Mahim creek suspended load during the two seasons were low, 25.0 and 19.0 mg.l $^{-1}$ respectively, nearly half of that observed at Versova creek. Phosphate values of Versova creek were very high during the post monsoon (31.0 µg at.l^{-1}) and low during pre monsoon (8.7µg at.l^{-1}). The corresponding values for Mahim creek were 6.0 and 22.7µg at.l^{-1}). The nitrate concentration of Versova creek showed very low value of 0.5µg at. l^{-1} during premonsoon compared to the level of 6.4 µg at. l^{-1} during post monsoon. In the Mahim creek the values were very high (nearly 4 times and 2.5times) during both seasons .The nitrite content showed the same concentration in both creeks during pre monsoon while the values were 2.9 and 0.6 µg at.l^{-1} at Mahim and Versova creek during post monsoon respectively. The level of ammonia was high during the two periods (24.5 and 18.6 µg at.l $^{-1}$) at Versova creek whereas the values for Mahim creek were 4.8 and 7.7µg at.l^{-1} for the pre and post monsoons.

The occurrence of NO_2-N in high concentrations is typical of coastal waters under considerable environmental stress. The nitrite is an intermediate product of bacterial oxidation of ammonia to nitrate. The concentration of PO_4-P, NO_2-N and NO_3-N in the creeks were high and variable suggesting enrichment due to anthropogenic releases in the region. Marked increase in the level of PO_4-P in the interior areas is indicative of influence of waste water. Suspended load in both the creeks was maximum in the interior stations. Rainfall is the most important cyclic phenomenon in tropical countries as it brings about important changes in the physical and chemical characteristics of the coastal environment.

In this study throughout the stations, the salinity was found to be high during pre monsoon season and low during the post monsoon season. 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, temperature and decomposition of organic matter(Karuppasamy and Perumal, 2000; Rajasegar, 2003; Paramasivam and Kannan, 2005). 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 ecosystems (Balasubramanian and Kannan, 2005; Sridhar et al., 2006). The recorded higher values (35.9PSU) at BS5 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; Rajasegar, 2003). The minimum salinity was recorded during the postmonsoon and the maximum was recorded during pre or summer season as reported earlier by Sundaramanickam et al. (2008). The recorded high pre or Summer pH(>8) at stations BS5 to BS1 and BY5 to BYM might be due to the influence of seawater inundation and biological activity and due to the presence of high photosynthetic organisms (Das et al., 1997; Santhanam, 1998). The observed higher values during postmonsoon compared to premonsoon at stations BSD and BSE 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 with higher values during postmonsoon, to freshwater flow and terrigenous impact of sediments.

Nutrients are considered as one of the important parameters in the estuarine environment influencing growth, reproduction and metabolic activities of biota. Distribution of nutrients is mainly based on the season, tidal conditions and freshwater flow from land source. Presently recorded high postmonsoonal values of NO_3 at BS1, BSB to BSE could be mainly due to the organic materials received from the catchment area during ebb tide (Das et al., 1997). The increased nitrates level at stations BS1, BSB to BSE during postmonsoon season 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). The recorded low values of nitrate 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 (Govindasamy et al., 2000).

The recorded higher premonsoon or earlier Summer nitrite values in the study area except at BSC 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). The recorded low nitrite values at BSC and <6 at all stations in Thane creek during pre or summer season 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 during monsoon/postmonsoon 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). Low Summer values (< 8) at stations BS5 to BS1 could be attributed to the limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton (Senthilkumar et al., 2002). 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). Higher concentration of ammonia observed during postmonsoon season at stations BS5 to BSA and at BYV and BYM (>15 ml.l^{-1}) 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).

Suspended load values are less variable except for a high value, 87 mg. l^{-1} at BSB and lowest value 13mg. l^{-1} at l^{-1} BSD during premonsoon and except the value 121mg. l^{-1} at BSB during postmonsoon and except for a high value, 89mg. at BYC during pre monsoon and except the high value 88mg. l^{-1} observed at BYE during post monsoon. The variation in the standardised values of the parameters is more in the Bassein creek (Fig. 2a) than Thane creek (Fig. 2b). High variations from the mean values are observed for suspended load (solids), PO_4, NO_3, and NH_4 in both the creeks. Significant difference between the two creeks was observed for temperature ($P<0.05$) during premonsoon and for salinity ($P<0.05$) during postmonsoon (Table 1a).

High density of zooplankton recorded in premonsoon season might be due to the stable salinity and high phytoplankton population density. The abundance of zooplankton during premonsoon season was also reported by Srinivasan and Santhanam (1991) in Pullavazhi backwaters, Karuppasamy and perumal (2000) in the Pichavaram mangroves, Madhu et al. (2007) in Cochin backwaters. The high densities of zooplankton might be the result of relatively stable environmental conditions, which prevailed during those seasons and due to the presence of great neritic elements from the adjacent seas. Further, salinity is the key factor influencing the distribution and abundance of zooplankton (Padmavati and Goswami, 1996).

Copepods community structure

Bassein creek

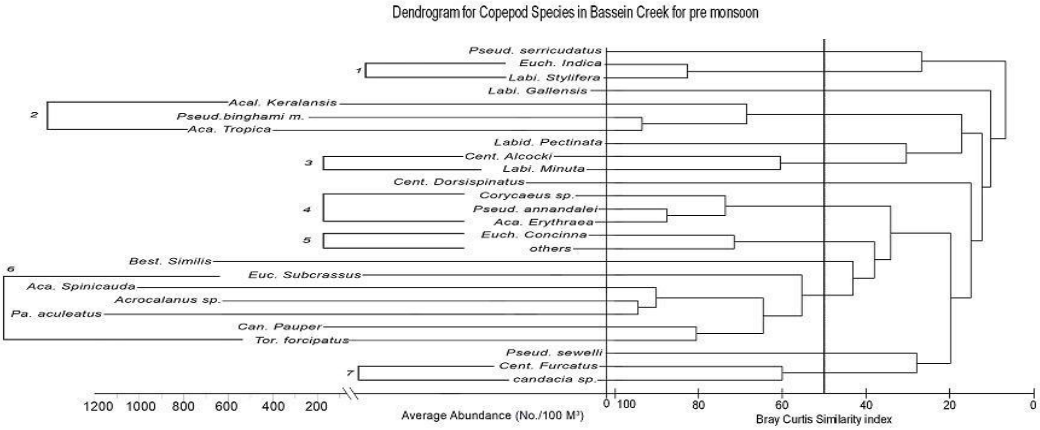
Dendrogram for Copepod Species in Bassein Creek for pre monsoon

Figure 3

Zooplankton in creeks is dominated by copepods. In Bassein creek during pre monsoon period the copepod percentage varied from 2.9 to 96.1% with an average percentage of 64.6% and density of 6301/100 $m^3$with the highest density 15698/100 m^3at BS4, in the coastal area away from the mouth and lowest density, 42/100 m^3 at station BSE, upstream. A total of 25 species were recorded. Acartia spinicauda was the most common and dominant species followed by Paracalanus aculeatus and Bestiolina similis. Highest diversity was observed at BS5, a coastal station and was contributed by many typical marine forms. Minimum diversity is recorded in BSE in the upper reaches. During post monsoon period the percentage of copepods varied from 0.1% to 83.7% with an average of 43.7% and density of 2018/100m^3. Highest percentage was observed at station BSA while maximum density (5830/100 m^3) was observed at station BS3 . The minimum density of 9/100 m^3 was observed at station BSD.

Premonsoon Period

A total of 25 species belonging to 14 genera were recorded from the Bassein creek during pre monsoon period .Acartia spinicauda observed at 9 stations, was the most common and dominant species occurring in all the 9 stations followed by Paracalanus aculeatus and Acrocalanus sp. occurring at 8 stations followed by Bestiolina similis, obtained from 4 stations. Canthocalanus pauper was absent from the inner most 3 stations. The contribution of Pseudodiaptomus binghami malayalus occurring at 4 locations, varied from 6 to 36 % at the inner most 4 stations with the highest percentage at station BSE. Acartia tropica and Acartiella keralensis were observed in the interior stations. A. keralensis was observed at two stations (BSC and BSD) contributing 9.0 and 2.9%. The rest of the species did not contribute significantly.

Eucalanus subcrassus and Tortanus forcipatus were recorded from 5 stations. Bestiolina similis and Euchaeta concinna were obtained from 4 stations while P. sewelli, Acartia erythraea, A.tropica and Corycaeus sp. from 3 stations .The remaining 12 species were from only one or two stations, contributing lower percentages to copepod population .

Post monsoon period

During this period, a total of 33 species belonging to 20 genera were observed from the Bassein creek. Acartia spinicauda was the most common species occurring at 8 stations and Canthocalanus pauper was present at 6 stations, being absent from the innermost 3 stations .Three species namely Acrocalanus sp. , Paracalanus aculeatus , and Tortanus forcipatus were present at 6 stations . Acrocalanus sp. contributed 4.5% to 22.2%, the highest percentage was noted at station BS2 and lowest at stations BSC. Paracalanus aculeatus was observed at outer stations the percentage contributions was maximum (31.1) at the interior stations (BSB) and the minimum (14.5) was observed at the outer most station (BS5) . Tortanus forcipatus was also observed from 6 stations from offshore to inshore . the percentage composition varied from 0.01 to 6.2. Bestiolina similis was present in 5 stations, in the middle stations the percentage ranging between 9.8 (BS3) and 28.2 (BS2).

Centropages dorsispinatus was present at 4 stations with a percentage contribution of 2.2% to 14.5%. Seven species namely Eucalanus subcrassus, Euchaeta concinna, E. indica, Pseudodiaptomus annandalei , Labidocera stylifera , Acartia erythraea and Acartiella keralensis were present in 3 stations. Out of these only Acartiella keralansis contributed significantly 2.2 (BS3) - 40.9% (BSC). E.pileatus, Centropages furcatus , Pseudodiaptomus serricudatus , P. bowmani , Temora turbinata , Calanopia elliptica , Labidocera gallensis , L. pectinata , Oncaea sp. and Corycaeus sp. were observed only in 2 stations , the percentage varying between 0.1 to 3.5 . P. ardjuna, P.sewelli, Pseudodiaptomus binghami malayalus, Labidocera minuta , Pontella diagonalis , Microsetella sp. and Oithona sp. were recorded only from one station. The number of species observed from the Bassein creek varied from 1 to 25. Maximum number was recorded from station BS5 and minimum number from station BSD.

Thane creek

Premonsoon period

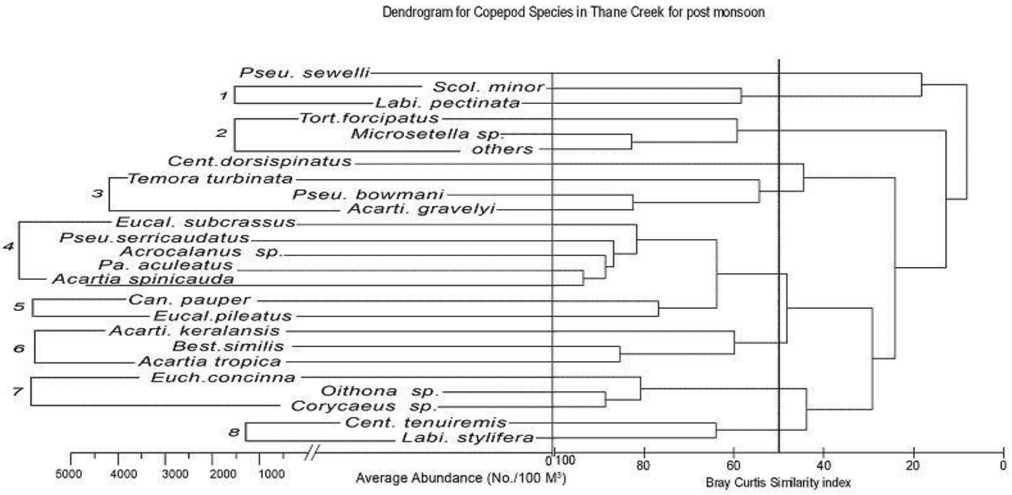

Figure 6

At Thane creek during pre monsoon the percentage of copepods varied from 3.0 % at station BYC to 99.5 % at station BYD with an average of 54.1 % and density of 3709/100 m^3. Highest density 10779/100 m^3 was found at station BY2 and the lowest density of 112/100 m^3 at BYC. During post monsoon the percentage composition of copepods varied from 1.0 % (BYC) to 83.0 % (BY4) with an average percentage of 51.1% . During this period the highest density of 57485/100 m^3 (BY4) and lowest density 7/100 m^3 (BYC) with an average density of 10924/100 m^3 was observed.

During premonsoon season 35 species belonging to 19 genera were encountered. Acartia spinicauda was the most commonly occurring species ,the percentage composition of which varied between 2.8 and 33.1 % in station BYD and BYB respectively. Seven species namely Euchaeta concinna , E. indica , Centropages furcatus , Pseudodiaptomus serricudatus , Tortanus forcipatus, Acartia centrura and Corycaeus sp. occurred in 5 stations . Except Tortanus forcipatus and Acartia centrura all other species were seen in < 5% contribution to copepods population. Tortanus forcipatus shared 3.2 in BY5 and BY4 to 7.5 % in BYE . Pseudodiaptomus binghami malayalus, Acartia erythraea, Acartiella keralansis, A.gravelyi , Labidocera stylifera were present at 4 stations of which, Acartia erythraea was present in the offshore stations alone contributing 3.2 (BY3) to 12.2 % (BY2). For Acartiella keralansis the minimum was observed at station BYB and maximum (35 %) at BYE . Centropages alcocki ,Temora turbinate , Calanopia elliptica were observed from 3 stations and contributed lower percentages. C.corsini, Pseudodiaptomus annandalei and Candacia bradyi were encountered from 2 stations . Four species namely Labidocera pectinata, Labidocera minuta , Pontella diagonalis and Oncaea sp. were observed from single station only and formed low percentage contribution to copepod population. The number of species recorded from the different stations varied from 9 to 27 with maximum from outermost station BY5and minimum from BYC in the upstream area.

Postmonsoon period

During the post monsoon period a total of 25 species belonging to 17 genera were encountered . Acartia spinicauda was the most abundant and common species occurring in all the nine stations, the percentage varying between 0.2 and 53.2 % ,the highest contribution of the species was obtained from BY4 and the lowest was in the station BYE . Eucalanus subcrassus was recorded from 8 stations with a minimum of 0.2 % at station BYD and maximum of 6.7 % at station BY1 . Paracalanus aculeatus was recorded from 7 stations contributing 9.3% at station BY3 to 24.7% at BY2. Acrocalanus sp. was present in 7 stations and ranged from 2.1(BY4) to 13.7% (BY1). Pseudodiaptomus serricudatus was present at 6 stations, the density ranging from 2.3 (BYB) to 17.4 % (BY5). Acartia tropica was observed from 6 stations, the percentage ranging from 3.3 % at station BYB to 31.7 % at BYD . Acartiella keralansis was observed from 5 stations the percentage varying from 2.1 % at station BY4 to 58.2 % at BYC . Canthocalanus pauper was present at the outer 4 stations (1.0 (BY2) to 12.8 % (BY4)). Eucalanus pileatus, Centropages dorsispinatus , Labidocera pectinata and Corycaeus sp. were recorded from 3 stations and broadly varied from 0.2 to 8.3 % . The rest of the species namely Euchaeta concinna, Centropages tenuiremis , Temora turbinata, Tortanus forcipatus and Acartiella gravelyi and Oithona sp. were encountered from 2 stations with varying percentage contribution .Species like Scolecithricella minor, Pseudodiaptomus bowmani , Pseudodiaptomus sewelli , Labidocera stylifera and Microsettella sp. were found to be rare occurring only in one station with varying percentages. The number of species recorded from different stations varied from 3 at BYC to 14 at BY3.

Versova and Mahim creek

In the versova creek during premonsoon period copepod contributed 71.5 % and density was 7663/100 m^3 . In the Mahim creek the percentage contribution of copepod to total zooplankton was 80.0% while the density was 178/100 m^3. During post monsoon period the percentage of copepods to total zooplankton at Versova creek was 47.9 with a density of 1247/100 m^3. In the Mahim creek the percentage of copepods was 83.6 with copepod density of 8764/100 m^3 .

During premonsoon Period in the Versova creek 5 species were noticed. Acartia spinicauda contributed 50.8%, Paracalanus aculeatus 24.3%, Acrocalanus sp. 12.3 %, Centropages tenuiremis 12.0 % and Tortanus forcipatus 0.6 %. During premonsoon period, three species were recorded from Mahim creek namely Acartia spinicauda which contributed 97.1 % of total copepod, Tortanus forcipatus 2.5 % and Bestiolina similis 0.4%. During post monsoon period four species were recorded from Versova creek with Bestiolina similis dominating with 51.6 % followed by Acartia spinicauda (29.0 %) and Acrocalanus sp. (16.2 %) . Oithona sp. showed very low percentage of 3.2 . In Mahim creek 6 species were recorded during post monsoon period with highest percentage of Bestiolina similis (85.5 %) . Other species namely Acartia spinicauda , Oithona sp. , Pseudodiaptomus bowmani , Canthocalanus pauper and Euchaeta indica showed low percentage (< 5.8%). Bestiolina similis formed the dominant species contributing 51.6 % in Versova and 85.5 % in Mahim creek .The next dominant species which occur in both stations was Acartia spinicauda followed by Oithona sp.

SPECIES DIVERSITY

In the Bassein sector during premonsoon period richness is on an average of 5.58 with 28.3 % variation (Table 1b) . High species richness was observed at BSB (8.55) and at BS1 (8.04). The species niche breadth ranges from 1.35 (Corycaeus sp.) to 6.26 (Acrocalanus sp.). Niche breadth for Paracalanus aculeatus and Acartia spinicauda were respectively 5.96 and 5.24 (Table 2).

Compared to premonsoon period, post monsoon season was more rich with a sharp decreasing gradient from station BS5 to BSE and average species richness is 7.65 with nearly 50 % more spatial variability than pre monsoon season. During postmonsoon season more uniformity (CV=1.38%) is observed in the species distribution pattern with higher average density than pre monsoon period (Table 1b) . The species niche breadth is much less than that observed during pre monsoon . High value for niche breadth is 3.44 ((Canthocalanus pauper) , 3.81 (Acrocalanus sp.), 3.81 (Paracalanus aculeatus) and 3.80 (Acartia spinicauda). All the other species have almost the same low niche breadth (Table 2).

During pre monsoon period at thane sector highest species richness was observed at station BY4 (16.90) and least (7.38) at station BYD . Species were distributed more evenly at station BYC (CV=2.47%) and BY2 (CV= 2.36%) . Shannon Weaver index was greater than 3 except at stations BYC , BYD and BYE . It showed a decreasing trend from station BY5 to BYC . Species dominance index was 0.84 on the average . Species niche breadth 6.65 for Paracalanus aculeatus with comparable values for Bestiolina similis (6.05) and Centropages dorsispinatus (6.31) .

Species richness, concentration and evenness factors are less variableat Thane sector during post monsoon season whereas diversity and dominance of species are spatially more variable . During post monsoon period community is rich (2.50). The species with high niche breadth were Bestiolina similis (4.26), Paracalanus aculeatus (4.01), Acartia tropica (4.55). The herbivore, carnivore and omnivore ratio observed in this area varied from 14 : 2 : 30 to 23 : 2 : 36 (Table 3) at Bassein creek and varied from 22:2:50 to 12:2:27 at Thane creek.

Coexistence and factor analysis

In both creeks number of differential groups are same. But number of species providing maximum information (Table 4) about the copepod distribution during pre monsoon period is higher at Thane creek (21) than at Bassein creek (13) . This causes the greater similarity in distribution at Thane creek than at Bassein creek. Even though there is no difference between the number of differential factor groups providing the maximum information about the copepod distribution during pre and post monsoon periods, there is an inverse comparison between Bassein and Thane creek during post monsoon with more number of species (19) contributing to the differential factor groups at Bassein creek than at Thane creek. The explained variability (Table 4) by the first 6 significant eigen values(factor groups) varied between 90% (Bassein creek premonsoon season) to 98% (Bassein creek post monsoon season). During both the seasons the species with similar abundance are clustered together in both the creeks. During premonsoon season, (Fig.3) in the Bassein Creek, out of 7 clusters obtained, clusters 2 and 6 are of species with abundance more than 600 ind. /100m^3 and the remaining are that of species with abundance less than 200 ind./100m^3 which correspond to the differential factor groups 2 and 1(Tables 5 and 6) whereas in the thane creek (Fig. 5), only cluster 4 out of 5 clusters with 17 species (with abundance >200 ind./100m^3) is a highly coexisting cluster with similarity >65% and it corresponds to the differential factor group 1 and the remaining are that of very rare species. During post monsoon season, (Figs.4 and 6) the pattern of clustering remained the same with rare and abundant species being separated in both creeks. Cluster 4 with 8 species in the Bassein creek (av. Abun. >200 ind. /100m^3, corresponds to differential factor group 2) (Tables 5 and 6) and cluster 4 with 10 species in the Thane creek (av. Abun. > 900 ind. /100m^3, corresponds to differential factor group 1) out of 5 clusters in each are the highly coexisting clusters during post monsoon season.

STEP-UP MULTIPLE REGRESSION ANALYSIS

Step-up multiple regression model is fitted to the data of premonsoon season at Bassein Creek. Total zooplankton abundance is observed to be influenced by DO, suspended load (SL) and PO_4-P. The equation is

$$\log ZOO = 0.776*10^{-3} + 0.657\ DO – 0.211\ SL + 0.370\ PO_4\text{-}P + 0.029\ DO*SL – 0.126\ DO*\ PO_4\text{-}P$$

$$+ 0.00496\ SL*\ PO_4\text{-}P \text{ ------------------------------}(1)$$

This model could explain about 40.82% of the total variability in the zooplankton abundance during pre monsoon ($F_{(6,3)}$ = 2.0348, P< 0.05). The order of importance of the model parameters could be given as

suspended load > DO * PO_4^-P > suspended load * PO_4^-P > PO_4^-P >DO * suspended load > DO

Similarly, in Bassein Creek for total copepods, the predictive variables are salinity (S), pH and DO. The equation is,

$$\log COP = 0.696*10^{-4} + 1.230\ S + 0.293\ pH + 0.405\ DO - 0.163\ S * pH + 0.125\ S * DO –$$

$$0.539\ pH*DO \text{ -------------------------------------}(2)$$

This model explains about 75.90% of the total spatial variation in copepod abundance ($F_{(6,3)}$ = 5.7235, P<0.05). The relative importance could be graded as S * pH > S > S * DO > pH * DO > DO > pH

During post monsoon season, for explaining total zooplankton abundance, the input variables obtained are salinity (S), suspended load (SL) and PO_4-P. The equation is,

$$\log ZOO = -6.602*10^{-5} – 0.105\ S + 0.971\ SL – 0.895\ PO_4\text{-}P – 0.0268\ S*\ SL +$$

$$0.0495S*\ PO_4\text{-}P\ – 0.0383\ SL * PO_4\text{-}P \text{ -------------------------------}(3)$$

This model explains about 95.79% of the total spatial variation in total zooplankton abundance ($F_{(6,3)}$ = 35.1527, P<0.001).The order of parameters could be given as SL > S* SL> SL* PO_4-P > PO_4-P > S* PO_4-P >S indicating that suspended load is the controlling factor followed by the limiting factors, PO_4-P and Salinity and together with their interaction effects.

The most important parameters for determining the copepod abundance at Bassein Creek during post monsoon season is observed to be temperature, PO_4-P and Nutrients ($NO3^-N$ + $NO2^-N$ + $NH4^-N$) (Nu) with 89.61 % V.E. followed by suspended load and PO_4-P combination which explains about 87.34% of the existing variability in the log copepod abundance. The advantage of having more variables in the former case over the latter case is insignificant (P > 0.05). Hence the model could be taken as,

$$\log COP= -5.484*10^{-4} + 0.0432SL - 0.160\ PO_4\text{-}P - 0.00173\ SL * PO_4\text{-}P \text{ ---}(4)$$

which explains about 87.34% ($F_{(3,6)}$ = 21.6745, P< 0.001). The order of importance of the parameters could be given as, SL > PO_4-P > SL * PO_4-P. When temperature is replaced with salinity, the model could enhance the V.E > by 6.57% which is again not a significant amount (P > 0.05).

In Thane Creek for explaining total zooplankton abundance during premonsoon season the ecologically important parameters obtained are temperature, salinity and PO_4-P. The equation is

$$\log ZOO = -1.259*10^{-5} - 0.0271\ T -0.278\ S - 3.434PO_4\text{-}P + 0.0109T * S + 0.123\ T$$

$$*PO_4\text{-}P\ - 0.0171\ S * PO_4\text{-}P \text{ ---}(5)$$

This could explain about 75.43% of the variability in zooplankton abundance distribution, ($F_{(6,5)}$ = 6.6273, P<0.05). The order of importance of the model parameters could be graded as T * PO_4-P > PO_4-P > S*PO_4-P > T * S > S > T. The salinity when replaced with pH or suspended load give almost the same (74.92%) explained variability. Since salinity could be measured more accurately than pH or suspended load, the first set of ecological variables could be preferred to predict total zooplankton abundance during pre monsoon season at Thane Creek. To predict total copepods at Thane Creek area during pre monsoon season, the most important predictive variables could be listed as salinity, pH, suspended load and nutrients (NO_3-N + NO_2-N + NH_4^-N)

The model is logCOP = - 4.539*10^{-5} + 1.261S – 3.558pH - 0.198SL – 0.346Nu + 0.00371S* pH – 0.0479S * SL + 0.00588 S * Nu – 0.0584pH * SL - 0.00681 pH *Nu + 0.276 SL * Nu.-----------(6)

This model could explain about 81.23% of the spatial variation in copepod abundance in Thane Creek during pre monsoon, ($F_{(10,1)} = 5.762$, $P< 0.05$). The order of importance of the model parameters could be given as SL * Nu > pH * SL > Nu > SL> S * Nu > S > S * pH > S * SL > pH > pH * Nu. On replacing pH with temperature about 78.76% of the variability could be explained, ($F_{(10,1)} = 5.0778$, $P< 0.05$).

In Thane Creek total zooplankton during post monsoon season was observed to be predictable from the above said parameters, Temperature, pH, Suspended load (SL) and Nutrients. The model is

ZOO= 8.986 + 4.526T - 23.084pH + 7.596SL - 4.429Nu + 12.0712 T*pH + 1.738 T*SL + 0.612 T * Nu + 11.097 pH * SL - 13.523 pH * Nu + 3.635 SL * Nu-------------------- (7)

This model could explain about 82.13% of the total spatial variability ($F_{(10,1)} = 6.0554$, $P< 0.05$) in zooplankton distribution. The order of importance is pH > T * pH > pH * Nu> pH * SL> SL > T > SL * Nu> Nu > T * SL > T * Nu implying pH, T, Nu to be the most important variables for total zoo in Thane Creek during post monsoon period.

In the case of total copepod during the post monsoon in Thane, The model is

COP = 0.132 + 2.374T - 2.098pH + 4.985DO - 0.0654PO_4-P + 1.0307T*pH + 8.455 T * DO + 1.0528 T * PO_4 + 9.487pH * DO - 10.361 pH *PO_4-P - 2.047 DO* PO_4-P --(8)

explaining 86.21% of variability in spatial distribution of copepods, ($F_{(10, 1)} = 7.88$, $P< 0.05$). The model parameters in the order of importance could be graded as pH *PO_4-P > T * DO > pH * DO > DO > T > pH > DO *PO_4 > T * PO_4 > T * pH. All these model parameters are highly significant except PO_4 and T * PO_4 ($P<0.01$).

Canonical Discriminant Analysis

Creeks behave distinctly different due to the significant variation in the distribution of temperature during postmonsoon and, salinity during premonsoon and also the variations in NO_2 and species's abundance during both the seasons. Seasonal discrimination is clearly depicted in the two creeks and the coastal stations by the discriminant score plot for premonsoon (Fig. 7) and postmonsoon (Fig. 8) based on all the species abundance and the water quality parameters. The seasonal discrimination is more of a unique nature during postmonsoon than during premonsoon season.

DISCUSSION

Like any other coastal marine environment copepods formed the most abundant group of zooplankton in the estuaries and coastal waters. For the Bassein sector the percentage contribution of copepods to total zooplankton varied from 0.1 to 96.1 with an average of 51.3 % and population density 4160/100 m^3. For Thane sector, the percentage contribution of copepods to total zooplankton varied from 1.0 to 99.5 with an average of 52.7 and density 7127/100 m^3 . In the Versova creek the percentage contribution of copepods was 59.7 and density 4455/100 m^3 . The percentage contribution of copepods for Mahim creek was 81.8 and density 4471/100 m^3 . The ratio of copepods in the Bassein : Thane : Versova : Mahim :: 10:17:11:11. Obviously Thane sector sustained higher density of copepods compared to the other 3 regions .The average density for the Bassein and Thane sectors for both the seasons recorded a value of 5643/100 m^3 . In the earlier study, Ramaiah and Nair (1997) obtained high density of copepods with an annual average of 207500/100 m^3 . The present value when compared with their observation, showed a decrease in copepod population by a factor of 37 . Tiwari and Nair(1993) reported that copepods in Dharamtar creek, southeast of the surveyed area contributed 71.8 % of total zooplankton with average density of 109300/100m^3 which is also very high compared to the present value .

A total of 25 species were recorded from the Bassein sector during pre monsoon and 33 species during post monsoon period with the corresponding values at Thane sector being 35 and 24. The number of species recorded from Versova and Mahim creeks were very less compared to the other two sectors. At Versova 5 and 4 species were recorded during pre and postmonsoon period with 3 and 6 species at Mahim respectively. From the Bassein sector maximum number of species viz. 13 and 25 were recorded during both pre and post monsoon period from BS5 which is the outer most station and the population was mainly composed of Paracalanus aculeatus, Acartia tropica, Canthocalanus paupe and Acrocalanus sp. During pre monsoon period minimum number of species, 5, recorded from BSE , the innermost station comprised of Pseudodiaptomus binghami malayalus , Acartia spinicauda , Eucalanus subcrassus , Acartia tropica and Centropages alcocki . During post monsoon period only one species namely Pseudodiaptomus sewelli was observed from BSD . Euchaeta indica , Centropages dorsispinatus , Pseudodiaptomus serricudatus , Labidocera stylifera were rare during pre monsoon period . During post monsoon Pseudodiaptomus ardjuna , Pseudodiaptomus sewelli , Pseudodiaptomus binghami malayalus , Pontella diagonalis and Acartiella gravelyi , Microsettella sp. and Oithona sp. were rare .

At Thane sector 35 species were recorded during pre monsoon period with BY5 recording 27 species . The main components are Acartia spinicauda , Paracalanus aculeatus , Bestiolina similis and Acartia tropica . The minimum number of species, 10, during pre monsoon was recorded from BYC. Acartia spinicauda, Pseudodiaptomus binghami malayalus, Paracalanus aculeatus, Bestiolina similis and Acartiella keralansis were the main species recorded . During post monsoon maximum number of species (14) were obtained from BY3 with Acartia spinicauda, Acrocalanus sp. and Canthocalanus pauper and Temora turbinata constituting the major share of the population .

In the Versova creek Acartia spinicauda and Paracalanus aculeatus, Acrocalanus sp. and Centropages tenuiremis were the main species during pre monsoon and Bestiolina similis, Acartia spinicauda and Acrocalanus sp. during post monsoon period , At Mahim creek 3 species were recorded during premonsoon period with Acartia spinicauda contributing the major portion with Tortanus forcipatus and Bestiolina similis contributing very little percentage . During post monsoon period Bestiolina similis was the most abundant copepod with Acartia spinicauda , Oithona sp. , and Canthocalanus pauper sharing < 6 % of the total population .

Ramaiah and Nair (1997) observed 46 species from the Bombay Harbour – Thane creek – Bassein creek . Nair and Ramaiah (1998) recorded 42 species from this area . In the present investigation only 35 species were obtained from the same environment . In the creek environment, Acartia spinicauda and Paracalanus aculeatus were the most common and dominant species . Ramaiah and Nair (1997) reported A. Centrura and Acartia spinicauda to be most common and dominant species .In a previous study Gajbhiye et al. (1991) obtained 68 species from the Versova and Mahim creek . Gajbhiye (1982) reported 49 species from the Thane creek . This study indicated reduction in the number of species. The number of species were decreasing towards the interior stations. At the interior parts water quality indicated influence of waste input leading to low levels of DO and high concentration of nutrients (Figs. 2a and 2b). This appears to have influenced the species diversity in this polluted creek environment.

In the nearshore waters salinity is the most important factor influencing the distribution of copepods (Pillai et al. , 1973 ; Goswami and Singbal, 1974 ; Goswami and selvakumar, 1977; Madupratap , 1979 ; Goswami, 1982 ; Ramaiah and Nair, 1997). Canthocalanus pauper, Eucalanus subcrassus, Eucalanus pileatus, Paracalanus aculeatus were more common and abundant in the outer stations . Low saline species namely Pseudodiaptomus binghami malayalus, Acartia tropica, Acartiella keralansis and Acartiella gravelyi were recorded from the interior stations where salinity was low . In the Bassein sector Acartia tropica was observed mostly from the upstream station. But in the Thane sector Acartia tropica was observed from the outer coastal stations . Pseudodiaptomus binghami malayalus was observed from all upstream stations during pre monsoon period . But during post monsoon period the species was observed only from the upper most station. In the Thane sector Pseudodiaptomus binghami malayalus was present in the upstream stations during pre monsoon period ,but was not recorded during post monsoon period. Euchaeta indica , ,Pseudodiaptomus serricudatus, Labidocera stylifera, Labidocera gallensis were rare in the Bassein creek during pre monsoon period . Candacia sp. , L. minuta , Pontella diagonalis , Microsetella sp. and Oncaea sp. were rare during post monsoon . At Thane sector also Labidocera pectinata and L. Minuta , Pontella diagonalis and Oncaea sp. were rare during pre monsoon . Scolecithricella minor , Pseudodiaptomus bowmani , Labidocera stylifera and Microsetella sp. were rare during pre monsoon period . Bestiolina similis, Acrocalanus sp. , Paracalanus aculeatus and Acartia spinicauda were the most common and tolerant species .

The present study showed a reduction in the total number of copepod species in this region which may

be attributed to the change in the environment. This study shows a distinct difference between rare and abundant species which are clustered separately in both seasons in both creeks. As revealed by the regression analysis there is a well defined and distinct difference between the two creeks as to the group of environmental factors which predict the total zooplankton abundance as well as copepod abundance in the two seasons. This observation is further substantiated by the canonical discriminant analysis which very uniquely separates the two creeks Bassein andThane more widely during postmonsoon season than during premonsoon season so also the Versova and Mahim creek from the former two (Figs 7and8). This suggests the seasonal uniqueness of the four creeks with respect to biological activities.

The principal systems that regulate pH of water are the carbonate system consisting of CO_2, H_2CO_3, HCO_3^- and CO_3^{2-}. Because of the buffering capacity of the sea water, generally seawater pH has limited variability (7.8-8.3). In shallow and biologically active tropical waters, large diurnal pH changes from 7.3 to 9.5 may occur naturally because of photosynthesis. In the nearshore and estuarine systems influx of fresh water particularly during monsoon can affect the buffering effect and the pH often remains below 8.0. These areas are also vulnerable to pH changes due to release of anthropogenic discharges. At both creeks at all stations during post monsoon season higher anthropogenic discharges are observed compared to premonsoon. Stations BSB to BSE at bassein creek and BYC to BYM at Thane creek are vulnerable to anthropogenic discharges during premonsoon season also.

Salinity is an indicator of freshwater incursion in coastal waters as well as excursion of seawater in inland water bodies such as estuaries, creeks and bays. Seawater salinity vary depending on evaporation, precipitation and freshwater influx. Higher salinity is observed with less variation at BS5 to BSA (30.5 –

30.3PSU) during postmonsoon and slightly higher variations (35.4 – 32.8 PSU) at stations BS5 to BSA during premonsoon season. Stations BSB to BSE are subjected to high variations with low level salinity (22.1 – 15.7) during premonsoon season and (20.1 – 13.7 PSU) during postmonsoon. Thane stations are less subjected to salinity variations except BYE and BYV (28.3 to28.7) during premonsoon season whereas at BYD and BYE high variation is observed (26.4 to 10.2 PSU) during postmonsoon season.

DO is of considerable interest in water quality investigations as its concentration in water is an indicator of ability of a water body to support a well balanced aquatic life. DO is replenished through photosynthesis, dissolution from the atmosphere and addition of oxygen rich water such as through run off. Simultaneously DO is consumed during heterotrophic oxidation of organic matter and respiration by aquatic flora and fauna as well as oxidation of some naturally occurring constituents in water. Thus equilibrium is maintained between consumption and replenishment of DO. At both the creeks less variation with higher values is observed atBS4 to BSA(4.8 – 5.7) during both the seasons. DO values were higher during postmonsoon at Bassein creek stations, whereas it is a reverse at Thane creek. DO values reduced to half at BSB to BSE of that of DO observed at BS5 to BSA during both seasons. At Thane creek the trend is reversed during postmonsoon.

In natural waters the rate of consumption of DO is lower than the rate of replenishment resulting in maintenance of adequate concentrations which are often at the saturation level. Influx of anthropogenic discharges containing oxidizable matter such as sewage and certain pollutants consume DO more than the water body can replenish creating under saturation which in extreme cases may lead to onset of septic conditions with mass odorous emissions thereby degrading the ecological quality.

Dissolved nutrients, though in low concentrations, are essential for the production of organic matter by photosynthesis. Among several inorganic constituents such as phosphate, nitrogen compounds, silicate, trace metals etc., the traditional nutrients namely phosphate and nitrogen compounds have a major role to play in primary productivity. However their occurrence in high levels in areas of restricted water exchange such as creeks, bays, and estuaries can lead to an excessive growth of algae which in extreme conditions result in eutrophication. Anthropogenic sources of phosphate in coastal marine environment include domestic sewage, detergents, effluents from agro-based and fertilizer industries, agricultural runoff, organic detritus etc. Domestic sewage contributes substantially to phosphate enrichment around urban settlements such as Mumbai where marine disposal of sewage is the preferred option.

Nitrogen cycle involving elementary dissolved nitrogen oxides: NO_3^-, NO_2^-; and reduced forms: NH_4^+, NH_3, plays a significant role in sustaining life in aquatic environment. NO_3^- is the end product of oxidation and the most stable form at pH 7. Biogenic decomposition of organic matter in water proceeds by the reduction of available oxidants in the sequence $O_2 > NO_3^-N > MnO_2 > Fe_2O_3 > SO_4^{2-} > CO_2$. In waters with high organic matter such as Mahim creek, the DO may be progressively depleted. Upon complete removal of DO, anaerobic micro organisms become important and further decomposition of organic matter continues through the use of NO_3^- as an oxidizing agent and then successively by $MnO_2 > Fe_2O_3 > SO_4^{2-}$.

When bacteria and other organisms decompose organic matter, part of the N in organic matter is converted to organic N in microbial biomass and the remainder is released to the environment as NH_3. NH_3 generated as a product of organic matter decomposition is oxidized to NO_3^- in an aerobic environment or builds up in water under anaerobic conditions. Domestic sewage that is released in large volumes to coastal areas of Mumbai is also an important source of urea in sea water. Wide use of urea as fertilizer is another source of the compound to the sea via agricultural runoff and river discharges. In seawater urea is decomposed to yield NH_3 and CO_2 and hence a potential source of NH_3 unionized ammonia (NH_3) is in equilibrium with ammonium ion (NH_4^+) at normal pH of seawater.

Due to insufficient mixing the lighter low salinity water preferentially remained at the surface resulting in the observed salinity difference between flood and ebb tide salinity at surface and bottom at Mahim creek. Stratification occurrence has been reported at Mahim bay (Zingde and Desai, 1980; Zingde and Sabnis, 1994).It has been reported that the sewage releases in the Mahim creek add 43 tons of suspended solids, 45 tons of BOD, 6 tons of nitrogen and 1 ton of phosphorus in the receiving water every day causing severe deterioration in the ecology of the creek. The effluent load retained in the estuary constituted 16% of the spring tide and 40% of the spring low tide volume of the creek during premonsoon .During the study on 18-21 August 2006 in the investigation of low saline water in the mahim bay (report 2006) the authors have observed that the character of the suspended load changed with increase of inorganic component from 50% in the creek to 65% in the bay and further to 80% in the offshore. The impact of the high organic loading was marginal outside the Bay mouth but within the Bay the DO replenished with the inflow of seawater during flood tide was quickly consumed leaving very low to undetectable levels in the northern bay unlike in the southern bay where some DO generally occurred. Low to undetectable concentrations of NO_3^--N and NO_2^--N and presence of sulphide along with high concentrations of NH_4^+-N during low tide indicated sulphate reduction in summer, the conditions under which the local ecology was severely impaired. The creek was generally devoid of DO, NO_3^--N and NO_2^-‾N in dry season except for brief periods of flood tide and the sulphide concentration exceeded75µmol/l. On the contrary during monsoon season the creek sustained high concentrations of NO_3^--N and NO_2^--N due to aerobic oxidation of organic matter by DO associated with monsoonal runoff. The high flux of NH_4^+-N transferred via the creek outflow was only partially oxidized in the

Bay leading to its high concentrations in the Bay water. The concentrations of PO_4^{3-}P were high in the Bay and the creek and often decreased with increase in salinity. Though the Muncipal Council of Greater Mumbai had diverted some of the domestic waste water through the marine outfall the water quality of the Mahim beach had not improved. It was estimated that $1.96x10^5 m^3/d$ wastewater continued to enter nearshore region through nonpoint sources that probably was responsible for the absence of significant improvement in water quality of nearshore areas subsequent to the diversion of sewage through the marine outfall. The high concentration of DO in samples during postmonsoon/monsoon was probably because of diffusion of atmospheric oxygen in water in the surf zone from where the samples were collected.

The ecological conditions in the creek environments of Mumbai shows evidence of deterioration of water quality due to anthropogenic and industrial waste input. The inflow from agricultural land also add to the enhancement of nutrients. Mumbai is the most populated city along the west coast and is a highly industrialised area. In the present study Acartia spinicauda was the dominant copepod in both the creeks. It is suggested that the species can be taken for eco-toxicological study as an index to the 'health status'of such environments.

. According to Marcus(2004) and Minutoli et al.,(2007) since Acartia spp are the main zooplankton in estuarine habitat forming critical components in the utilization of biotope acting both as grazers and predators they can be taken as zooplankton biomarkers. The percentage contribution of species in the interior stations reflect the pollution stress. The presence of Pseudodiaptomus spp in the upper reaches with heavy suspended load and nutrients indicate that the species can survive in adverse conditions. The decline in population density also serves as an index to evaluate the pollution status. Comparison with earlier studies in and around the present area of investigation indicates a reduction in species diversity as well as population density. Long-term monitoring of all the parameters along with toxicity studies using target species are essential to understand the impact of pollution on dominant copepod species. The copepod data indicates that the creek environment of Mumbai is an imperiled ecosystem. Restoration of the 'habitat health' is possible by stringent mitigation measures at government level and by civic initiatives to limit usage of hazardous chemicals.

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Table 1a. Distribution of water quality parameters and the student's t statistic for comparison between Bassein and Thane creeks											
		temp pre	temp post	salinity pre	salinity post	pH pre	pH post	DO pre	DO post	Sus. load pre	sus. load post
Bassein	Mean	31.20	25.70	28.21	24.51	7.91	7.67	3.93	5.07	41.29	37.90
Creek	std	0.68	0.32	7.90	7.80	0.36	0.31	1.42	1.50	21.66	30.18
	cv	2.18	1.24	28.00	31.82	4.49	4.08	36.25	29.55	52.47	79.63
Thane	Mean	31.08	27.12	34.10	29.78	7.75	7.71	4.31	4.25	45.50	35.08
Creek	std	0.66	1.11	2.82	6.32	0.32	0.18	1.67	1.12	18.17	20.97
	cv	2.14	4.08	8.28	21.23	4.10	2.40	38.71	26.46	39.93	59.77
	s	0.705	0.885	5.999	7.374	0.352	0.263	1.638	1.371	20.801	26.818
	student't statistic for Bassein creek and Thane creek for various parameters										
		0.414	-3.737*	-2.293*	-1.667	1.070	-0.340	-0.539	1.396	-0.473	0.245
		PO4 pre	PO4 post	NO2 pre	NO2 post	NO3 pre	NO3 post	NH4 pre	NH4 post		
Bassein	Mean	9.39	6.87	17.06	19.78	3.81	3.87	3.03	2.19		
Creek	Std	6.19	4.75	13.97	12.26	6.73	4.31	6.16	2.16		
	Cv	65.89	69.19	81.90	61.98	176.63	111.24	203.46	98.55		
Thane	Mean	11.32	6.68	10.13	10.58	2.09	2.67	3.59	3.43		
Creek	Std	13.79	6.26	8.51	8.61	3.43	2.72	6.73	5.44		
	Cv	121.84	93.82	83.93	81.37	163.80	101.81	187.46	158.84		
	S	11.541	5.902	11.875	10.939	5.450	3.700	6.797	4.481		
	student't statistic for Bassein creek and Thane creek for various parameters										
		-0.390	0.077	1.362	1.964	0.737	0.760	-0.193	-0.644		

*---- Calculated value of Student's t statistic is significant at 5% level ($P<0.05$)

Table 1b –Spatial distribution of characteristics defining community structure of copepods of of bassein and thane creek

Parameters	Margalef	Heips	Shannon Weaver	Pielou	Simpson
Bassein Creek Pre monsoon					
Average	5.58	1.19	2.25	0.93	0.74
σ	1.58	0.57	0.39	0.16	0.08
C.V%	28.31	10.59	17.64	17.64	47.81
Thane Creek Pre monsoon					
Average	11.54	1.57	3.16	0.85	0.83
σ	3.09	0.57	0.67	0.18	0.14
C.V%	26.8	16.43	21.16	21.16	36
Bassein Creek Post monsoon					
Average	7.66	1.38	2.38	0.69	0.75
σ	3.65	0.43	0.59	0.16	0.09
C.V%	47.69	11.28	25.6	30.93	22.54
Thane Creek Post monsoon					
Average	5.66	1.53	2.51	0.96	0.77
σ	1.46	0.49	0.6	0.23	0.09
C.V%	25.83	11.31	24.08	31.94	24.08

Table 2 – niche breadth for different species at Bassein and thane creek during pre monsoon and post monsoon periods

Species	Pre monsoon		Post monsoon	
	Bassein Creek	Thane Creek	Bassein Creek	Thane Creek
Canthocalanus pauper	2.27	3.44	3.67	1.79
Eucalanus subcrassus	2.57	1.99	4.27	3.41
Eucalanus pileatus	-------	2.07	4.44	2.45
Bestiolina similis	3.13	2.51	6.36	4.26
Acrocalanus sp.	6.27	3.81	5.77	3.69
Paracalanus aculeatus	5.97	3.82	6.66	4.02
Euchaeta concinna	3.21	2.87	2.93	1.98
Euchaeta indica	------	2.98	3.48	-------
Centropages dorsispinatus	-------	1.71	6.39	2.47
Centropages tenuiremis	-------	1.67	4.38	1.94
C. alcocki	2.09	-------	2.36	2.78
Centropages furcatus	0.72	1.37	3.18	-------
C. orsini	-------	-------	1.98	-------
Pseu. serricaudatus	-------	-------	3.18	1.39
pseu. bowmani		1.99	4.14	1.87
Pseu. sewelli	2.83	-------	3.22	2.36
Pseu. binghami m.	2.55	1	1.37	------
Pseu. annandalei	1.4	2.82	1.9	4.55
Temora turbinata	-------	1.62	2.08	2.65
candacia bradyi	1.93	-------	2.75	3.58
Tortanus forcipatus	3.55	2.3	3.42	1.12
Calanopia elliptica	-------	1.89	1.83	-------
Labidocera stylifera	-------	1.68	1.71	------
Labidocera minuta	1.57	-------	--------	-------
Pontella diagonalis	--------	-------	-------	--------
Acartia erythraea	1.54	2.88	4.87	-------
Acartia spinicauda	5.24	3.81	6.38	-------
A.tropica	2.62		5.08	-------
Acartiella keralansis	1.59	1.74	2.47	--------
Acartiella gravelyi	-------	--------	2.21	--------
Oncaea sp.	------	1.75	2.55	-------
Oithona sp.	-------	-------	-------	1.75
Corycaeus sp.	1.35	1.98	2.27	2.03

Table 3- Herbivore, Carnivore and Omnivore ratio for copepod species Bassein Creek and Thane Creek during Pre monsoon and Post monsoon periods

	Pre monsoon	post monsoon
Bassein	H: C: O	H: C: O
	23:02:36	07:01:15
Thane	12:02:27	11:01:25

Table 4 – Variability explained (%) for different factor groups obtained using R-mode analysis in Bassein and Thane Creeks during Pre monsoon and Post monsoon periods

Factor groups	Bassein Creek premonsoon	Thane Creek premonsoon	Bassein Creek postmonsoon	Thane Creek post monsoon
1	33.49	33.12	35.67	25.67
2	16.44	22.15	20.34	25.54
3	13.16	11.92	12.67	9.76
4	10.49	8.31	7.96	9.34
5	8.04	15.98	6.34	8.89
6	8.86	5.43	12.77	7.89
7	8.49	-	-	11.32

Table 5 – Differential factors groups (F.G) of species based on R-mode factor analysis for Bassein and Thane creeks during Pre monsoon period

Stations	Group 1	Group 2
Bassein Creek	Canthocalanus pauper, Eucalanus subcrassus, Acrocalanus sp., Paracalanus sp., Pseudodiaptomus sp., Tortanus forcipatus, Acartia erythraea, Acartia spinicauda Corycaeus sp.(Fig. 3, cluster 6)	Pseudodiaptomus binghami m, Centropages alcocki., A.tropica, Acartiella keralansis (Figure 3, cluster 2)
Thane Creek	Eucalanus subcrassus, Paracalanus sp. Euchaeta concinna, Euchaeta indica, Centropages dorsispinatus, Centropages tenuiremis ,Pseudodiaptomus serricaudatus, Pseudodiaptomus sewelli, Tortanus, forcipatus, Acartia erythraea, A.tropica, Oithona sp., Corycaeus sp., Bestiolina similis (Fig. 5, cluster 4)	Temora turbinata, Labidocera pectinata, Labidocera minuta, Labidocera stylifera, Pontella diagonalis, Centropages alcocki (Fig.5, clusters, 3, 5)

Table 6 – Differential factors groups (F.G) of species based on R-mode factor analysis for Bassein and Thane creeks during Post monsoon period.

Stations	Group 1	Group 2
Bassein Creek	Euchaeta concinna , Centropages tenuiremis, Pseudodiaptomus annandalei, Temora turbinate, Canadacia sp., Labidocera gallensis, Labidocera minuta, Labidocera stylifera , Pontella diagonalis, Acartia erythraea, Microsetella sp., Oncaea sp., Corycaeus sp. (Fig. 4, clusters 2, 3)	Acrocalanus sp. Centropages furcatus Tortanus forcipatus Labidocera pectinata Acartia spinicauda Acartiella keralansis (Fig. 4, cluster 4)
Thane Creek	Canthocalanus pauper , Eucalanus pileatus, Eucalanus subcrassus , Paracalanus sp. Pseudodiaptomus serricaudatus , Acartia spinicauda (Fig. 6, cluster 4)	Acrocalanus sp. Euchaeta concinna Temora turbinate, Labidocera stylifera Oithona sp. Corycaeus sp. (Fig. 6, cluster 5)

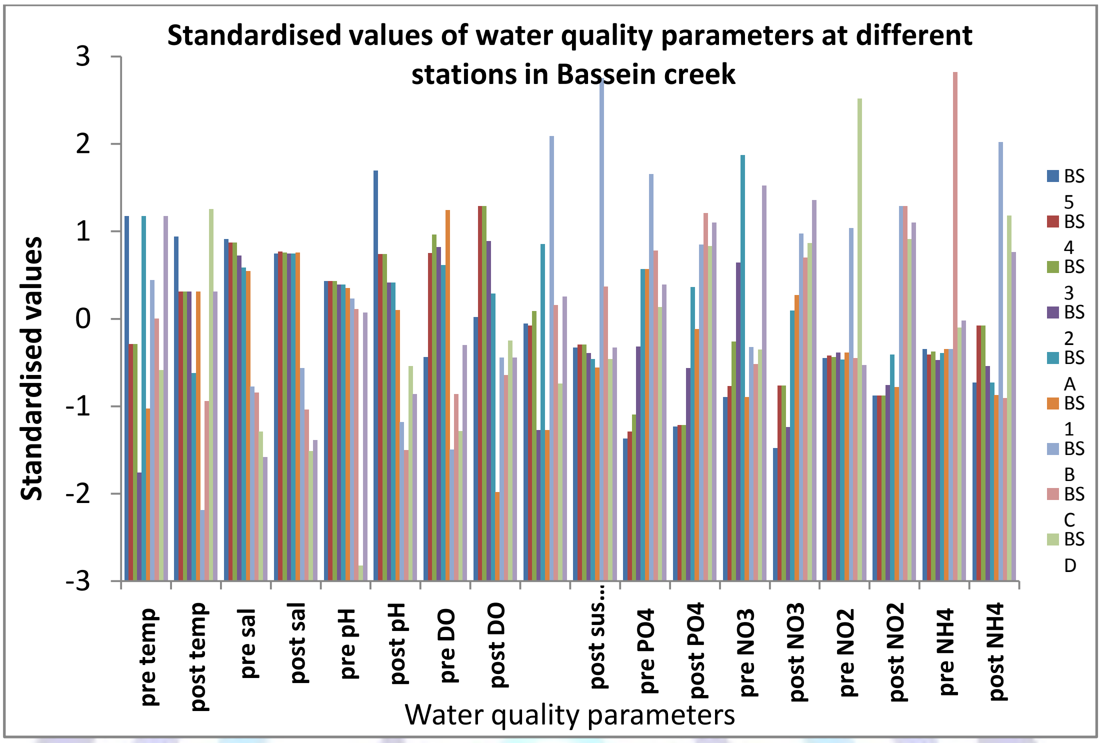


Figure 2a

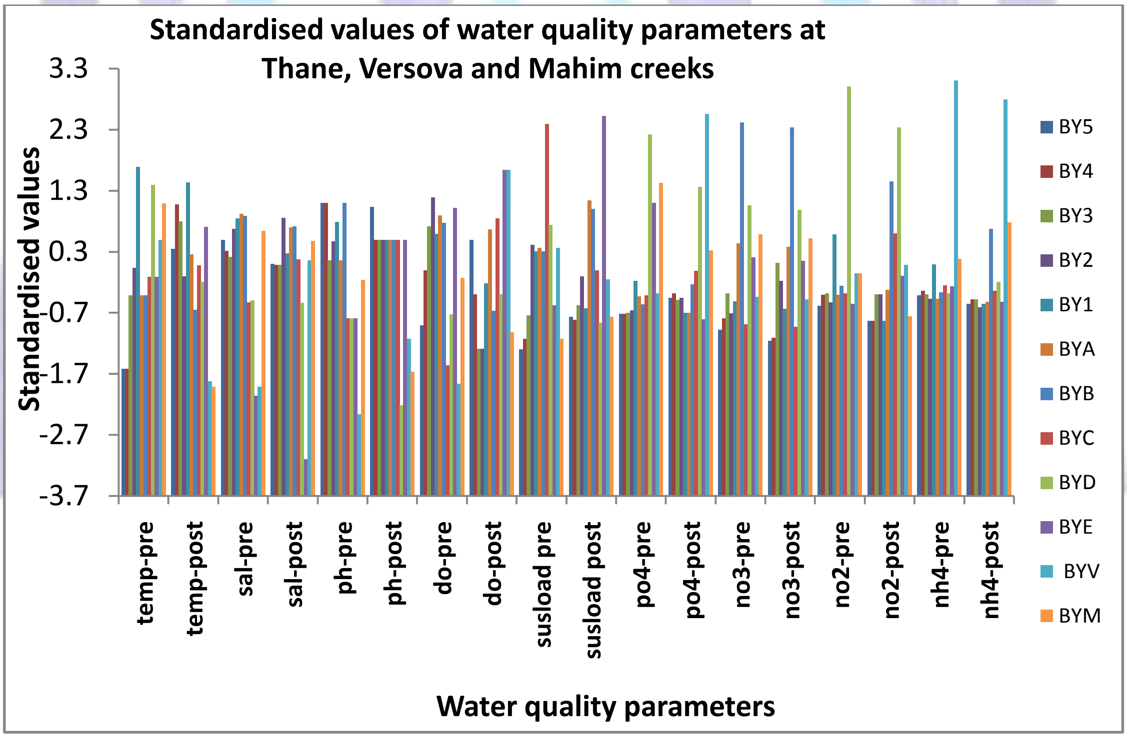
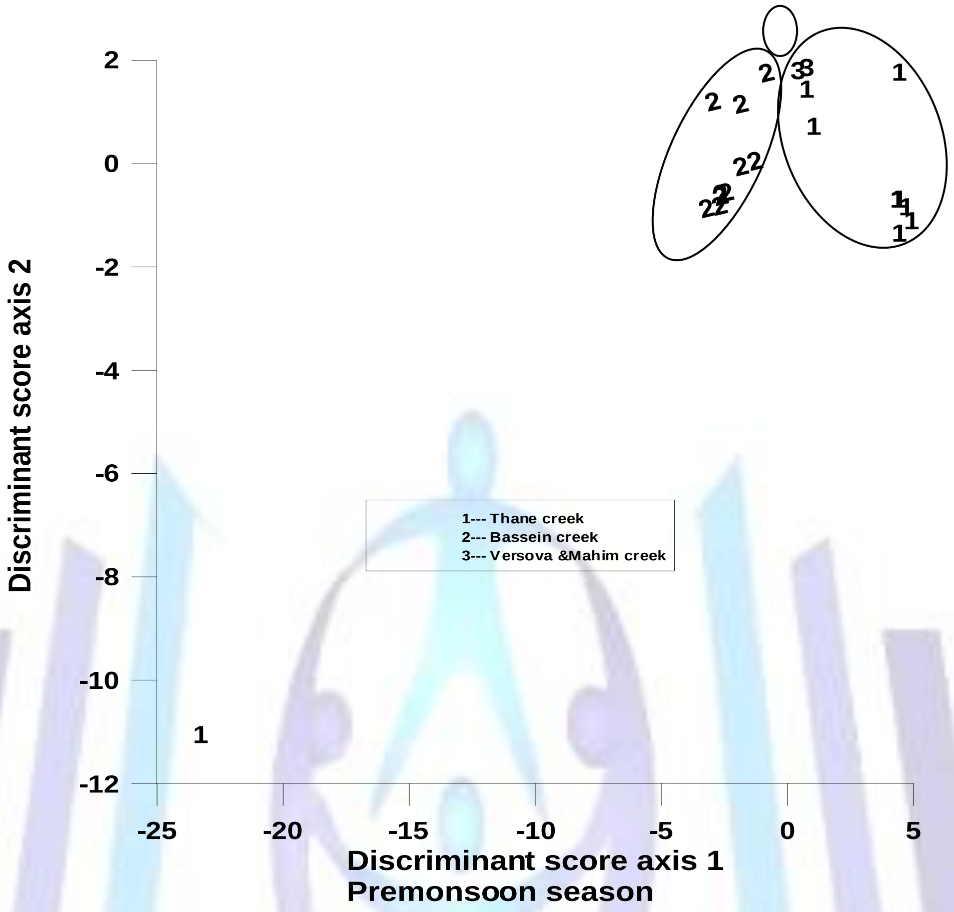


Figure 2b


Discriminant score axis 2
2
0
-2
-4
-6
-8
-10
-12
-25
-20
-15
-10
-5
0
5
Discriminant score axis 1
Premonsoon season
1--- Thane creek
2--- Bassein creek
3--- Versova &Mahim creek

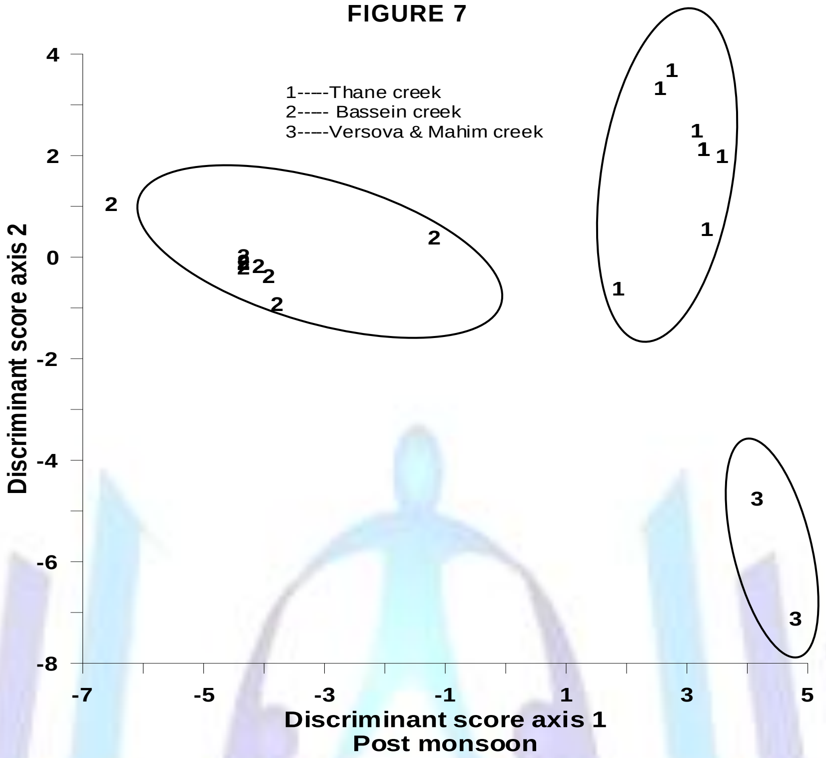


FIGURE 7
1----Thane creek
2---- Bassein creek
3----Versova & Mahim creek
Discriminant score axis 2
4
2
0
-2
-4
-6
-8
-7
-5
-3
-1
1
3
5
Discriminant score axis 1
Post monsoon
1
2
3

Figure 8