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EFFECT OF POLLUTION ON BENTHIC COMMUNITIES IN THE VISAKHAPATNAM HARBOR, EAST COAST OF INDIA

VADIVUKKARASI.P Research scholar, PG & Research Department of Zoology, Periyar Arts College, Cuddalore, Tamil Nadu, India
R. PERIYANAYAGI Research supervisor, PG & Research Department of Zoology, Periyar Arts College, Cuddalore, Tamil Nadu, India Email: rperiya1981@gmail.com
AG.CHINNADURAI PG & Research Department of Zoology, Periyar Arts College, Cuddalore, Tamil Nadu, India.

Abstract
Visakhapatnam harbor is a semi-enclosed water body on the east coast of India, is subject to a high degree of pollution caused by industrial and urban wastes. The community structure of macro and meiobenthos at six stations in Visakhapatnam harbor showed that the two components were affected by pollution. A limited number of species were dominant in polluted areas i.e. Capitella sp., Perna indica, Daptonem conicum Theristus sp., Rotalia translucens and Rosalina globularis. Macrobenthos comprised of polychaetes, bivalves, amphipods and isopods and their total densities ranged from 230 to 887 individuals m–2 (mean ±513 No.m-2). Meiobenthos was represented by 3 taxa and their total density ranged between 10 and 492 nos. 10 cm-2. The macrobenthos were numerically dominated by polychaetes, followed by bivalves, whereas isopod was less and sporadically represented. Nematodes were the dominant meiobenthic taxa followed by foraminiferans and harpacticoid copepods. A total of 19 species of macrofauna and 34 species of meiofauna were identified. There was also a trend of greater abundances of macro and meiobenthos in Entrance Channel compared to the other stations. Hydrographic studies and sediment quality assessment indicate severe effects of pollution at all the stations, except Entrance Channel, it has less pollution. There was significant spatial variability in each location, which may have obscured some effects of sediment contamination. The multivariate analyses detected differences in community composition which could be related to the pollution gradient. Therefore, it may conclude that presence of environmental factors and chemical data of sediment strongly reflected on benthic community structure.

Keywords: Macrofauna, meiofauna, distribution, species composition, pollution

1. Introduction

It is well know that human activity may influence the marine environment, and therefore, play a role in the development of populations, taxocenoses and communities. At end of the 20th century new habitats and communities have been formed due to the introduction of a large number of chemical wastes in the marine environment. The discharge of anthropogenic chemical contaminants into the environment can have profound effects on natural ecosystems (Vitousek et al. 1997, Peterson 2001). Identifying how chemical contaminants influence communities of organisms presents a much greater challenge because the chemical properties of contaminants, biological/ chemical interactions, and the demographic rates of impacted populations vary dramatically with environmental conditions (Underwood & Peterson 1988, Schmitt & Osenberg 1996). A better understanding of the ecological effects of pollutants and how they vary with environmental factors will improve our ability to detect and mitigate the impacts of anthropogenic activities in marine ecosystems.

Attributes of benthic community structure, species composition, quantitative parameters, trophic groups and the sets of species indicators may therefore reflect the quality of the marine environment. The benthos can integrate conditions over a period of time rather than reflecting conditions just at the time of sampling, so benthic animals are therefore more useful in assessing local effects in monitoring programs (Bayne et al. 1988, UNESCO 1986, 1988). Although bottom macrofauna have many advantages as indicators, benthic assemblages are extremely complex a wide size range of organisms and usually a large number of species. Because of this, the benthic community approach to biological effects monitoring has been criticized on the ground that sample analysis is so time consuming (Bayne et al. 1988, UNESCO 1986, 1988, Warwick 1988a).

Working at the species level often makes a comprehensive comparative study of this nature impracticable within the financial and time constraints usually imposed on biological impact studies. It is important therefore to assess the “appropriate taxonomy” required to detect community responses to anthropogenic disturbances, including pollution. There have been recent indications that analysis at taxonomic levels above those of the species may provide an equally clear if not clearer picture of the effects of contaminants (Heip et al. 1988, Herman & Heip 1988, Warwick 1988b,c).

Polychaetes, bivalves and crustaceans are dominant among the macrobenthic forms and are considered as good environmental indicators. In addition, many polychaete species have a high level of tolerance to adverse effects, both to pollution and natural perturbations (Gray & Pearson 1982, Levings et al. 1985, Rygg 1985a, 1985b, Burd & Brinkhust 1990, Dauer 1984, 1997, Samuelson 2001, Belan 2003). Generally, meiobenthos are also considered as better indicators of pollution due to their large numbers, small size, relatively short generation time, high fecundity and flexible feeding habitats (Heip 1980, Fleeger & Chandler 1983, Hicks & Coull 1983, Sandulli & De Nicola-Gludiei 1990, Kim et al. 2000). Additionally, some of the meiofaunal species are known to have good resistance to experimental conditions and exhibit various behavioral changes in response to environmental fluctuations (Hicks & Coull 1983, Miliou 1993, Ingole 1994).

In India, much of the research conducted on benthic fauna in coastal areas (Ansari et al. 1990, Vijayakumar et al. 1991, Suresh et al. 1992, Ansari et al. 1994, Chatterji et al. 1995, Prabha Devi et al. 1996, Ajmalkhan et al. 2005, Venkataraman & Mohideen Wafar 2005, Altaff et al. 2005), but there is little published information on assessing the effect of different kind of pollution on benthic fauna (Varshney et al. 1984, Varshney 1985, Raman & Adiseshasai 1989, Varshney & Govindan 1995, Ansari & Ingole 2002, Ingole et al. 2006) and none in Visakhapatnam harbor. Visakhapatnam harbor is a semi-enclosed water body on the east coast of India, is subject to a high degree of pollution caused by industrial and urban wastes. Therefore, in the present study has been undertaken in this area.

The aim of this paper is evaluate marine environment quality at the area study using environmental parameters, sediment chemistry data and characteristics of the benthic community structure and species composition and ecological indices.

2. Materials and methods

2.1. Study area

The study was carried out in the Visakhapatnam harbor, Bay of Bengal (Fig.1). The harbor plays a crucial role as the middle point distribution base for Southern, Eastern, Central and Northern states of India. Described as the “Brightest Jewel” of all Indian major ports for its outstanding performance and productivity, Visakhapatnam Port serves as a catalyst in spurring domestic and international trade.

Visakhapatnam harbor is located on the east coast of India (17°41'17.92"N, 83°17'34.00"E). Topographically, the harbor can be divided into two regions, inner and outer. The construction of the outer harbor in 1976 brought in its wake further changes, the most important of which was an increase in stagnation. A number of industries (oil refinery, fertilizer factory, zinc smelter, Hindustan Polymers, dairy plant) have developed in the immediate environment of the harbor, which use the harbor channels as a conduit of their effluents. In addition, the harbor also receives appreciable quantities of domestic sewage from Visakhapatnam Township, which creates the bulk of organic pollution in this area. Six sampling stations were chosen for the present study: namely Entrance Channel (EC), Northern Arm (NA), North Western Arm (NWA), Sinclair Canal (SC), Turning Basin (TB) and Western Arm (WA).

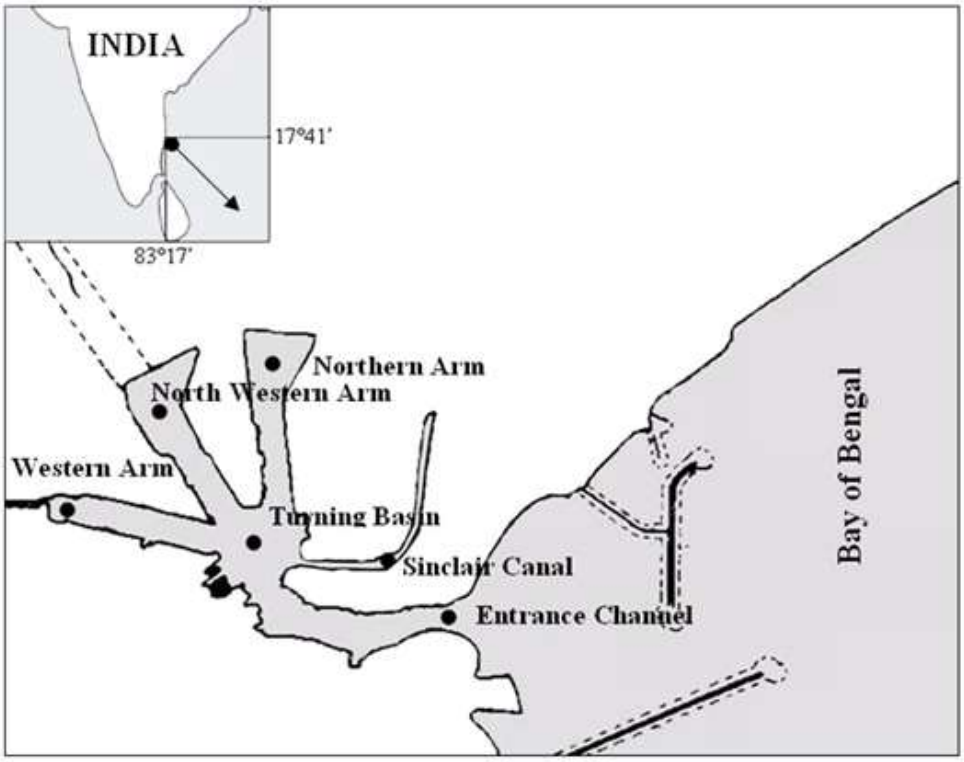

Fig. 1. Map showing the location of sampling sites at Visakhapatnam harbor

2.2. Sampling
The sediment samples were collected at seasonal intervals from June 2021 to April 2022. Samples for macrofauna was collected using a Peterson grab (0.0256m2 area) and meiofauna was sampled with a plexiglass core tube (dia. 3cm) thrust into relatively undisturbed grab sample. Four replicate samples were collected on each sample. The larger organisms were picked out and the sieved through 0.5mm mesh screen for macrofauna, but return on 63µm mesh screen for meiofauna. The organisms returned by the sieve were preserved in 5% formalin and stained with Rose Bengal. The benthic organisms were identified and counted under a binocular and high power microscope. The density of macrofauna is expressed as a no.m-2 and meiofauna as no. 10cm-2.
Sediment samples were also collected separately to analyze of grain size (Buchanan 1984), organic carbon (El Wakeel & Riley 1956) and heavy metals (Watling & Watling 1976). Analysis of physico-chemical parameters of the surf-water like temperature, salinity, pH and dissolved oxygen were also carried out.
2.3. Statistical analysis
The abundance data were analyzed using PRIMER software. Package from Playmouth Marine Laboratory (PML) (Clarke & Warwick 1994). Multivariate analyses were carried out on Bray-Curtis similarity index and non-metric Multidimensional Scaling (MDS).

3. Results
3.1. Physico-chemical parameters
Spatial, temporal and seasonal fluctuations in selected waters quality parameters viz. temperature, salinity, pH and dissolved oxygen were noticed in the study area, showed fairly uniform trend of variations (Fig. 2). The sampling stations did not show much variation in temperature (air and water). Dissolved Oxygen showed higher values in Entrance Channel as compared to the other stations, whereas it was almost nil or very low, especially during pre-monsoon in the Sinclair Canal (SC).
3.2. Sediment characteristics

The sediment was silty clay at all the stations, except Entrance Channel, it had less silt and clay content (Fig. 3). Sand particle (>62µm dia.) were present in negligible proportions. The concentration of TOC and heavy metals in the sediment ranged from 2.71 to 12.39 mg/g in TOC (mean 6.19±3 SD), 7.5 to 59.95µg in Lead (mean 27.01±16 SD), 2.35 to 51.89µg in Cadmium (mean 17.28±14 SD) and 15.5 to 55ng/g in Mercury (mean 26.59.19±10 SD). The TOC and heavy metal concentration was high at all the stations, except Entrance Channel (Fig. 3).

3.3. Macrofauna

3.3.1. Total density

The abundance of macrofauna varied from 230 to 887 no.m-2 (mean=513 ± 201 SD, n=24). Remarkably, high density was observed at Entrance Channel of the harbor during summer (887 no. m–2) and post monsoon (854 no. m-2) seasons (Fig. 4). Nonetheless, the macrofaunal density was dominantly observed at Turning Base (656 no.m-2) during monsoon season (Fig. 5).

In general, the macrobenthos were numerically dominated by polychaetes constituting from 21.0 to 100% and bivalves which contributed 16.0 to 73.7% of the total macrofauna. Other groups, such as amphipods and isopods were observed occasionally and accounted for less than 3% of the total macrofauna in all zones (Fig.4).

3.3.2. Species composition

A total of 19 species of belonging to polychaetes (13 species), bivalves (3 species) and crustacean (2 species) were identified. Dominant and co-dominant species varied from site to site. Dominant species included Capitella sp., Ophelia capensis, Glycera alba, Cirratalus sp., Sabellides sp., bivalve spats, Perna indica, Amitheo sp. (Table 1). Only one species namely Capitella sp., occurred in all the stations and also highest density. Distribution of indicator species in polluted sites (NA, NWA, SC, TB and WA) showed consistent density. Among the macrofauna, polychaetes were always dominated in all the sampling sites followed by mollusks (Table 1).

3.4. Meiofauna

3.4.1. Total density

Three major meiofaunal groups were identified, namely nematodes, foraminiferans and harpacticoids. Their density fluctuated between 10 and 492 no.10cm–2 (mean = 91 ± 121 SD, n = 24) (Fig. 6). Apart from the Entrance Channel, in all seasons had relatively higher densities of meiofauna than those with other five stations. Meiofauna community was dominated by nematodes, but in some stations they were replaced by foraminiferans as the dominant group. The harpacticoid copepod was found less frequently (Fig. 7).

3.4.2. Species composition

The species composition of meiobenthos is given in Table 2. A total of 34 species of meiofauna were identified during the present study. The most abundant and frequent species were Daptonem conicum, Theristus sp., Viscosia sp., Quinqueloculina sp., Rotalia translucens and Rosalina globularis (Table 2). The most of the species (19 species) were poorly represented and also occurred sporadically, while 4 species were moderately abundant (1-20%). In addition, 2 species namely Cornoboides advena and Tripyloides gracilis were constrained at North Western Arm. The highest species diversity of meiofauna was found at Entrance Channel and lowest at Sinclair Canal (Table 2).

In general, the highest density of macro and meiobenthos were recorded at Entrance channel (EC). It could also be seen from that the MDS and similarity analyses of macrofauna (Fig. 8) and meiofauna (Fig. 9) showed distinct assemblages of fauna between less (EC) and highly polluted stations (SC, TB, WA, NWA and WA).

Table 1. Occurrence and distribution of macrobenthos at all the stations of Visakhapatnam harbor (EC-Entrance Channel; NA-Northern Arm; NWA-North Western Arm; SC-Sinclair Canal; TB-Turning Basin; WA-Western Arm).

Species name	Summer						Pre-monsoon						Monsoon						Post monsoon					
	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA
Polychaetes																								
Polydora ciliata	+																		+					
Platyneries sp.	+																		+					
Capitellla sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Syllis sp.	+	+	+			+							+					+	+	+			+	
Nephtys	+					+	+						+	+			+	+	+		+		+	+
Glycera alba													+		+				+	+			+	
Ophelia capensis	+												+						+					
Ancistrosyllis parva													+	+		+	+	+	+					
Cirratalus sp.	+												+		+		+	+	+	+	+	+	+	
Cirriformia sp.														+									+	
Notomastus					+											+	+					+		
Phyllodoce sp.																								
Sabellides sp.																								+
Bivalves																								
Bivalves spats	+	+	+	+	+	+													+				+	+
Donax cuneatus																								+
Perna india	+		+		+	+	+	+	+	+	+	+		+	+		+	+		+	+			+
Amphipods																								
Ampitheo sp.	+			+	+								+	+					+	+				+
Gammaropsis sp.													+	+					+	+	+		+	
Isopods							+			+													+	+

Table 2. Occurrence and distribution of meiobenthos at all the stations of Visakhapatnam harbor (EC-Entrance Channel; NA-Northern Arm; NWA-North Western Arm; SC-Sinclair Canal; TB-Turning Basin; WA-Western Arm).

Species name	Summer						Pre-monsoon						Monsoon						Post monsoon					
	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA	EC	NA	NWA	SC	TB	WA
Nematodes																								
Daptonem conicum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Theristus sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Viscosia sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Halalaimus gracilis	+			+	+	+			+															
Desmodora sp.	+	+	+	+		+							+				+		+				+	
Metachromadora remanei	+						+	+			+	+	+				+	+	+				+	+
Halichoanolaimus dolichurus	+								+															
Enoploides sp.													+				+						+	
Pselionema sp.	+												+				+		+				+	
Tirssonchulus oceanus	+												+						+				+	
Oncholaimus sp.																	+							
Desmoscolex falcatus																			+				+	
Tripyloides gracilis																			+					
Harpacticoid copepods																								
Metis sp.										+	+													
Tisbe furcata	+						+						+						+				+	
Diarthrodes sp.													+				+		+				+	
Stenhelia sp	+						+												+					
Foraminiferans																								
Textularia agglutinans													+						+		+			
Quinqueloculina sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+			+	
Eponides repandus	+	+	+		+	+							+						+					
Triloculina sp.	+		+		+	+	+	+	+	+	+	+	+				+	+	+				+	+
Ammodiscus sp.	+					+																		
Leptohalysis sp.	+				+		+	+	+	+	+	+	+				+		+				+	
Rotalia translucens	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+
Asterorotalia trispionsa																			+	+	+			
Rosalina bradyi	+	+	+		+	+							+				+		+				+	
Rosalina globularis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nonion depressulum	+	+	+	+	+	+							+		+		+	+	+	+		+	+	+
Bolivina abbreviata							+	+		+	+	+							+					
Spirillina latesepata													+						+					
Spirillina limbata													+				+		+				+	
Ammotium sp.													+											
Ammoniun beccarii																			+					
Cornoboides advena																					+			

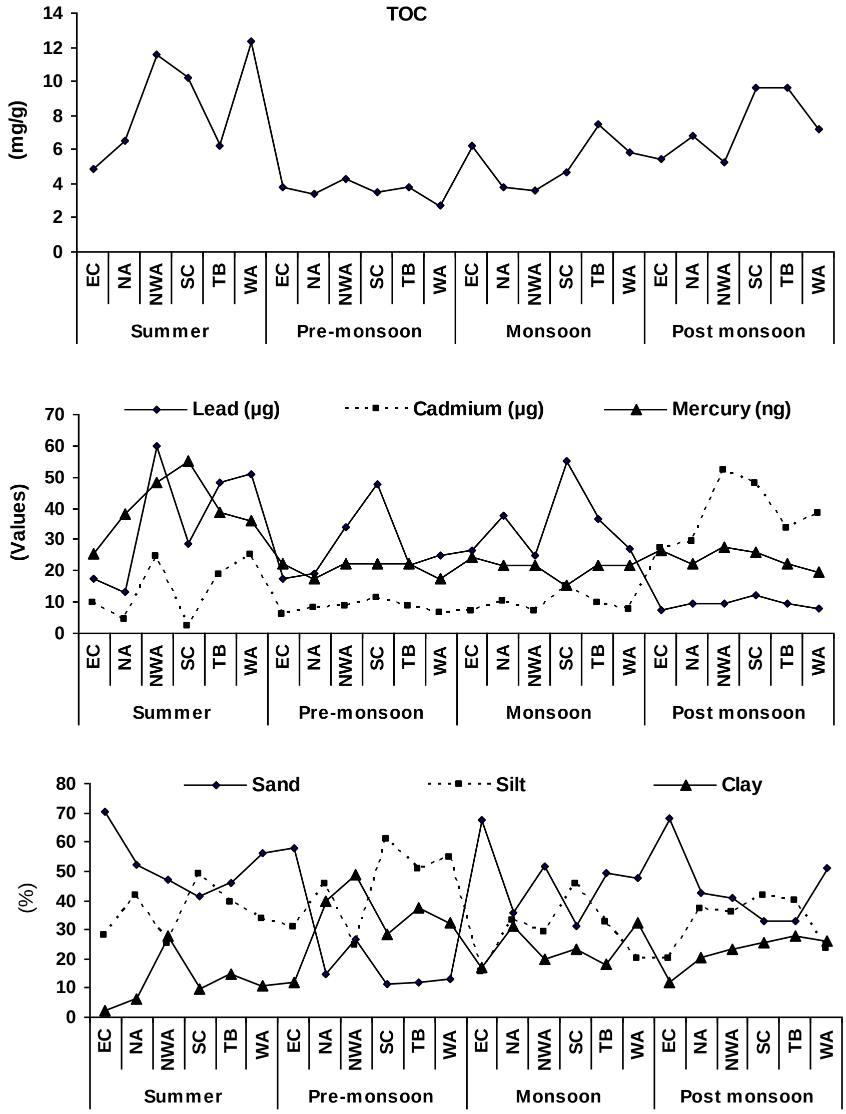

Fig. 3. Seasonal fluctuation of sediment quality at Visakhapatnam harbor during June 2021 to April 2022 (average of 4 replicates).

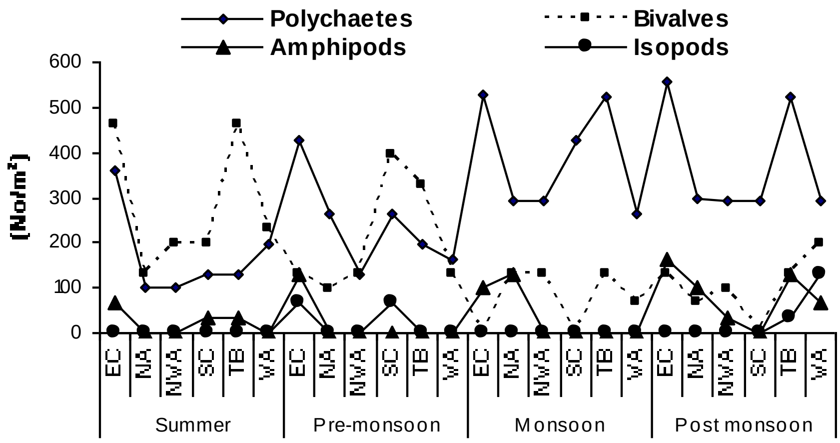

Fig. 4. Total density of macrobenthos at all the stations of Visakhapatnam harbor (Average four replicate samples per site).

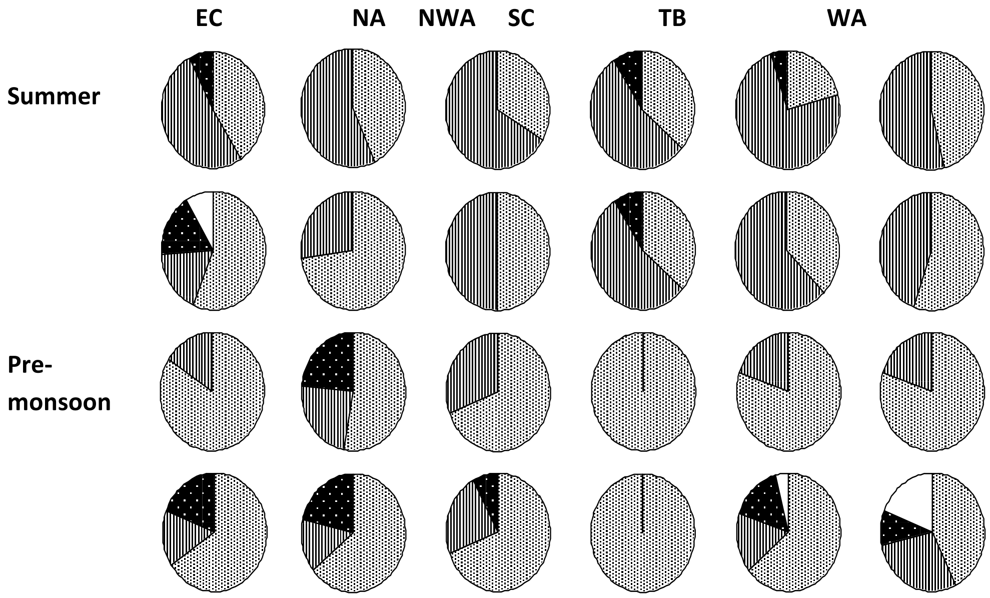

Fig. 5. Relative contribution of macrobenthic taxa at all the stations in the Visakhapatnam harbor. Values are given for macrofauna sampled in all the seasons and presented in percentage of the macrofauna density of four replicate samples per site, a full circle being 100% (EC-Entrance Channel; NA-Northern Arm; NWA-North Western Arm; SC-Sinclair Canal; TB-

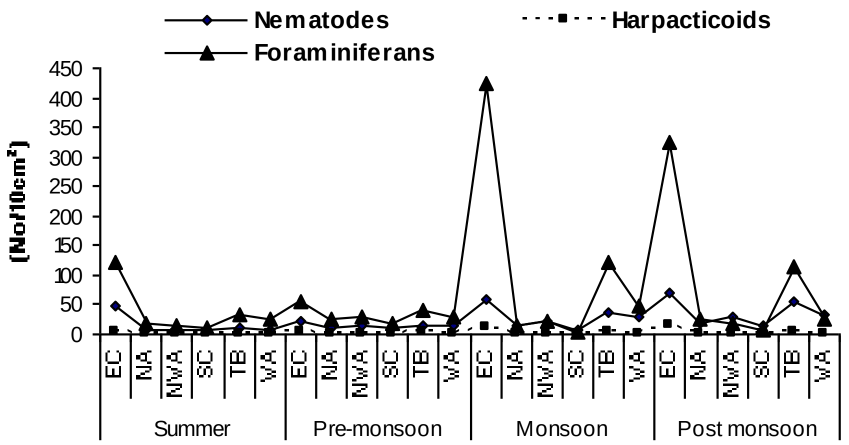

Fig. 6. Total density of meiobenthos at all the stations of Visakhapatnam harbor (Average four replicate samples per site).

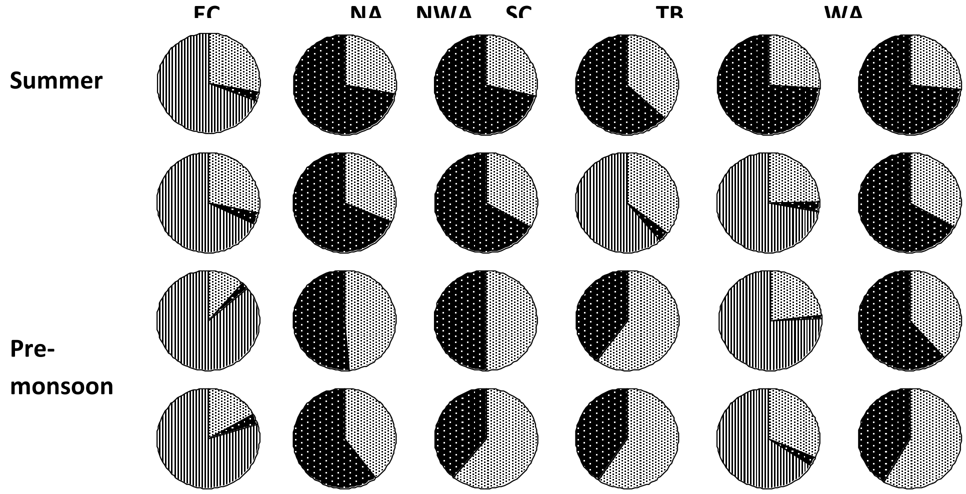

Fig. 7. Relative contribution of meiobenthic taxa at all the stations in the Visakhapatnam harbor. Values are given for meiofauna sampled in all the seasons and presented in percentage of the meiofauna density of four replicate samples per site, a full circle being 100%. (EC-Entrance Channel ; NA-Northern Arm; NWA-North Western Arm; SC-Sinclair Canal; TB-Turning Basin; WA-Western Arm)

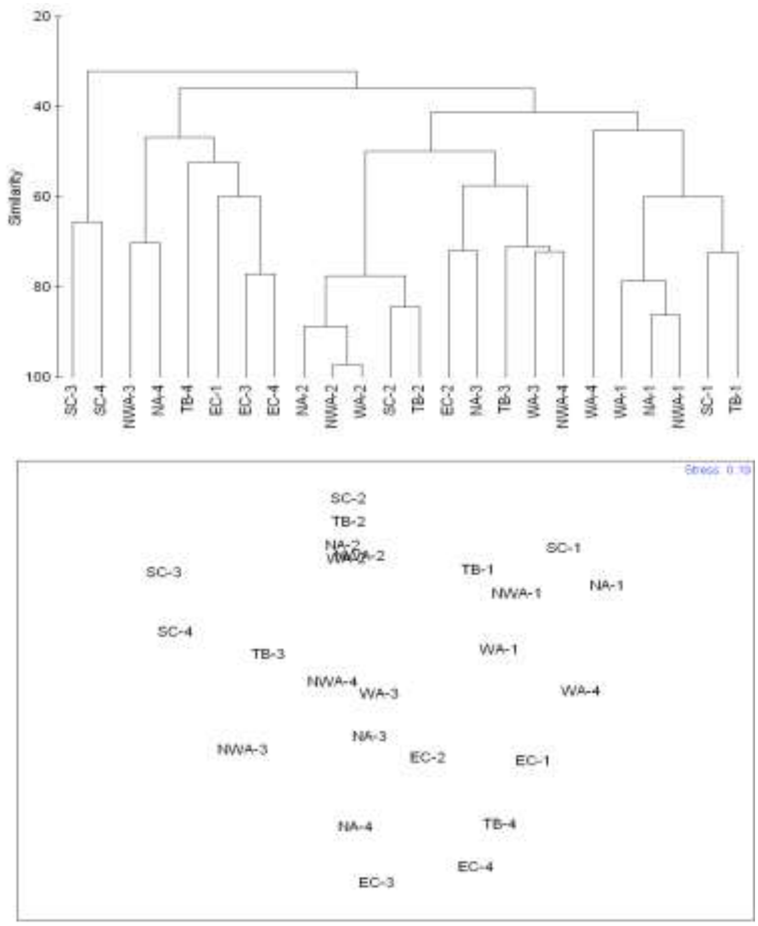

Fig. 8. Similarity and Multi-Dimensional Scaling (MDS) ordination of macrobenthic species composition at Visakhapatnam harbor (EC-Entrance Channel: NA-Northern Arm: NWA-North Western Arm: SC-Sinclair Canal:

4. Discussion

Hydrographic conditions showed that the salinity, pH and dissolved oxygen were fairly uniform trend of variations. The DO values were almost low or nil at all the stations, except Entrance Channel. Reduced oxygen levels could be due to the increased benthic biomass and respiratory activities of some aerobic bacteria, especially those that can mineralize hydrocarbon after an input of oil products (Bakke et al. 1982). The concentrations of TOC and trace metals were abnormally high in this locality, due to high organic load. It was under severe pollution stress and it was slightly decreased towards Entrance Channel, because dilution and assimilation capabilities of the water mass. Thus, an increasing trend in density and diversity of benthic fauna from SC, TB, NA, NWA and WA to EC is evident. The increase in organic content of the sediment is reflected in the nematode and copepod densities.

In the present study, highest density and diversity of macro and meiobenthos were observed at Entrance Channel and lowest at Sinclair Canal (SC). The other stations (TB, WA, NWA and WA) had sustained relatively moderate fauna. The authors reported that all the stations of this harbour are more polluted, due to the maritime activities and domestic wastes. Although the present results revealed a deteriorating condition at all the stations, the organic pollution in the horbour waters of Visakhapatnam has not yet reached an alarming level. However, macro and meiofaunal densities and diversity of the present study are comparatively poor than the previous reported from the unpolluted environment of coastal regions (Raman & Adiseshasai 1989, Ansari et al. 1990, Vijayakumar et al. 1991, Suresh et al. 1992, Ansari et al. 1994, Chatterji et al. 1995, Prabha Devi et al. 1996, Venkataraman & Mohideen Wafar 2005, Altaff et al. 2005). Reduction in the total and species level of meiofaunal abundance after contaminations with hydrocarbons bas been demonstrated both in natural and in laboratory experiments (Friethsen et al. 1985, Sandulli & De Nicola-Gludiei 1990, Danovaro et al. 1995).

The macrobenthos was numerically dominated by polychaetes followed by bivalves. Other groups namely amphipods and isopods were observed occasionally. The results of the present study indicated that annelids (mainly polychaete worms with opportunistic life history strategies from the family Capitellidae) respond positively to organic enrichment at all but the highest levels of toxic contamination, and arthropods respond negatively to toxicants with or without co-occurring organic enrichment. The positive response of annelids to organic enrichment has long been recognized (Pearson & Rosenberg 1978). Arthropods decreased with toxic contamination, but also responded negatively to high levels of organic enrichment. Arthropods probably responded negatively to increasing TOC because most species were subsurface-dwelling amphipods, isopods and cumaceans that were exposed to hypoxia/anoxia or toxic hydrogen sulfide (Lenihan et al. 2003), both of which result from the microbial decomposition of organic material. Pollution effects were also modified by the burrowing depth of the fauna.

Several papers have showed experimentally that amphipods are very sensitive to oil especially to aromatic components which have a high toxicity (Lee et al. 1977, Percy 1977, Gesteira & Dauvin 2000). Sanders et al. (1980) suggested that ampeliscid amphipods could be excellent indicators of oil pollution. Nevertheless, ampeliscids were not present in all soft-bottom communities, so all amphipods living in such communities could be considered as indicators of oil pollution (Swartz et al. 1982). For the soft-bottom communities, an inverse relationship appeared between species richness and abundance of amphipods, but observations proved that some species are favoured by organic, metallic or oil pollution (Bellan 1980).

During the present study, the polychaetes dominated in number of species and individuals at Entrance Channel. In contrast, *Capitella perarmata* and *Ophryotrocha notialis* are the most common genera of polychaetes found in organically enriched sediments in Antarctica (Lenihan & Oliver 1995) and in other regions of the world (Pearson & Rosenberg 1978). In fact, after various disturbances, several changes were observed: (i) an increase in abundance of opportunistic taxa such as opportunistic polychaetes, oligochaetes and nematodes and, (ii) a decrease and low abundance of the species considered to be sensitive to the pollution. Similarly, in the present study *Capitella* sp was predominantly observed at all the sampling sites.

Among the meiobenthos, crustaceans are most oil sensitive and die due to oil toxicity (Jewett et al. 1999). Moore and Stevenson (1997) reported that harpacticoid and amphipod abundances showed similar responses to pollution from gas platforms in the Gulf of Mexico. However, the N/C ratio is directly influenced by granulometry which affects nematodes and copepods in different manners, nematodes preferring mud and copepods sand. The copepods are generally susceptible to pollution stress (Coull et al. 1981, Dauvin 1998, Gesteira & Dauvin 2000) and nematodes are normally extremely resilient (Heip 1980). Nematodes and copepods were decreased with increasing pollution (Hodda & Nicholas 1985). Nematodes were dominated only unpolluted sites (Coull & Wells 1981), and even there at moderate density. It is well known that many species of foraminiferans are sensitive to pollution (Yanko & Flexer 1991, Yanko et al. 1994, Alve 1995, Alve & Olsgard 1999). The foraminiferans are rare occurrence of pollution (Hussain et al. 2006). This was corroborated in the present study.

In the present study, *Daptonem conicum*, *Theristus* sp., *Viscosia* sp. and *Rosalina globularis* were predominantly observed in all the stations. The analysis of nematode feeding groups, *Daptonem conicum* and *Theristus* sp are non-selective deposit feeder, since “nonselective deposit feeders” (1B) feed on all kinds of organic debris as well as living microorganisms. Whereas, *Viscosia* sp. has been shown to feed on scavengers (Moens & Vincx 1997). Generally, *Rosalina globularis* is a tolerant species in turbid waters (Hussain et al. 2006). Probably due to the reason, the above species were predominantly observed at all the stations. Lambshead (1984) raised the possibility that nematode and copepod populations may be influenced independently by various ecological factors, perhaps including pollution, and that the simple ratio is inadequate and difficult to relate to environmental parameters.

In general analysis of the benthic fauna, the highest density was recorded at Entrance channel. The Entrance Channel has less pollution compared to the other five stations, which had highly polluted environment. The low abundance of meiofauna could be related to the low concentrations of organic matter and bacterial density representing the primary food sources (Montagna et al. 1983, Montagna 1984, Rudnick et al. 1985). It could also be seen from the MDS and similarity analyses of macrofauna (Fig. 7) and meiofauna (Fig. 8) showed distinct assemblages of fauna between less (EC) and highly polluted stations (SC, TB, WA, NWA and WA), whereas the presence of *Capitella* sp., *Notomastus* sp., *Daptonema* sp. *Theistus* sp. *Viscosia* sp. and *Rosalina globularis* were predominantly observed at polluted sites. Such difference is largely due to relatively high TOC, trace metals and clay contents in these sites. Lowest similarity (30%) of macrofaunal species composition was observed between Sinclair Canal and other stations, while lowest similarity (40%) of meiofauna was observed between Entrance Channel, Turning Base and other stations. However, these differences probably have been caused by anthropogenic factors, namely sediment pollutions and influence of H_2S. The distribution of soft-sediment benthos has been related to sediment characteristics such as particle size, organic matter content, microbial associations, food availability (review by Snelgrove & Butman 1994). The abundance of benthos is clearly observed in sandy clay sediments followed by silty sediments. Clay supports a very poor benthic population indication that the median particle size harbours more population than the fine particle size (Harkantra et al. 1980). In the present study also, a lower density of benthic fauna was observed at all the stations, except Entrance Channel. All the stations had clayey sediments. The less clay content was observed at Entrance channel, which had highest abundance.

5. Conclusion

A major conclusion of our study is that the direct effects of chemical contaminants on sediment infaunal community structure appear clearly. Sediment quality analysis indicated that all the stations were more affected by contaminants in bottom sediments, whereas low pollutant concentrations were observed at Entrance Channel. MDS technique and cluster analysis of benthic community structure in all the stations, except Entrance Channel (EC) according to dissimilarity of species composition. MDS technique and cluster analysis demonstrated sharper differences between Entrance Channel (EC) and other stations (SC, TB, WA, NWA and WA). These stations having the similar environmental variables, because it was situated around the harbor. This may evidence of an influence of contaminants in Visakhapatnam harbor, because pollution often leads to structural changes in bottom communities. The sediment quality assessment using the benthic community indicated severe adverse effects at Sinclair Canal (SC), North Western Arm (NWA), Northern Arm (NA), Turning Basin (TB) and Western Arm (WA) and less effect on benthic community in the Entrance Channel (EC). Thus, benthic community may be used as an indicator in environmental quality assessment.

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