Impact of Anthropogenic Activities on Macrobenthic Communities of West Coast of India

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In
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Certificate

This is to certify that the thesis entitled "Impact of Anthropogenic activities on macrobenthic communities of West coast of India" submitted by Ms. Sanitha Sivadas for the award of the degree of Doctor of Philosophy in Marine Science is based on her original studies carried by her under my supervision. The thesis has not been previously submitted for any other degree or diploma in any Universities or Institutions.

Date: 05 December, 2008
Place: Dona Paula, Goa.

All the corrections indicated by the referees have been incorporated at appropriate places in the thesis

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Declaration

As required under the University ordinance 0.198(vi), I state that the present thesis entitled "Impact of anthropogenic activities on macrobenthic communities of West coast of India" is my original contribution and the same has not been submitted ony previous occasion. To the best of my knowledge the present is the first comprehensive work of its kind from the area mentioned.

The literature related to the problems investigated has been cited. Due acknowledgement have been made whenever facilities and suggestions have been availed of.

Sanitha

Sanitha K. Sivadas

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General Introduction

1.1 Introduction

Ecosystems are the productive engines of the planet, providing us with everything we need. Earth's ecosystems and human beings are bound together in a complex symbiosis. The coastal ecosystems are regions of remarkable biological productivity and high accessibility. They encompass a broad range of habitat types and harbours a wealth of genetic diversity, energy and minerals. Coastal ecosystems also recycle nutrients, filter pollutants, and help to protect shorelines from erosion and storms (Burke et al. 2001). Besides being areas of immense ecological significance, coastal regions are of huge economic importance, either as fishing grounds, ports or sites for industry and in more recent times have become recreational havens and a source for tourism. Therefore, the services provided by coastal ecosystems are less readily quantified in absolute terms, but are also invaluable to human society and to life on earth. This has made the coastal areas centers of human activity for millennia. It is not by chance that virtually all of the world's major cities are located on coasts and an estimated ≈50% of the world's population lives within the coastal regions (Sharpe 2005).

Assessment of the coastal ecosystem shows that the quality of coastal systems worldwide is on a decline caused by human induced environmental degradation. Halpern et al (2008) based on an ecosystem-specific, multi-scale spatial model indicated that no area is unaffected by human influence. Further, the study also reports that large fractions of the ocean ecosystem (41%) are strongly affected by multiple drivers. Consequently, the non-living and living resources in the marine coastal ecosystem have become progressively depleted. This, in particular is true of the fishery resources, which has failed to recover in many parts of the world (Botsford et al. 1997). Based on the analysis of commercial fish catch data from 64 large marine ecosystems spanning from 1950 to 2003, Worm et al (2006) projected global collapse of all currently occurring fish taxa by mid-21st century (100% loss of commercial fishes by 2048). The article was criticized and considered a pessimistic and inaccurate by many workers (Jaenike 2007; Hölker et al. 2007; Willberg and Miller 2007).These data may be an exaggeration of the human impact on the marine ecosystem and status of coastal pollution. Nevertheless, the gradual deterioration of the coastal waters across the globe and the failure of recovery of the marine ecosystem even after the cessation of human interference have demanded for increasing comprehensive and comprehensible ecological assessment from societal, economic and political heads. If we do not manage the marine pollution properly from a holistic environmental point of view, we stand to lose out in the future.

1. 2 The Indian Coastal Ecosystem

India has a vast coastline of about 8118 km, including the two offshore islands. The coastal area of the country comprises of vast network of backwaters, estuaries, creeks, lagoons, beaches and specialized ecosystems such as mangroves, sea grass and coral reefs (Ingole 2005). India's vast coastline has an exclusive economic zone of 2.015 x 10^6 km^2, which is 61% of the land area. The country has 14 major, 44 medium and 162 minor rivers with a total catchments area of 3.12 x 10^6 km^2, discharging 1645 km^3 of freshwater every year to the seas around the country. The important major rivers are Ganga, Mahanadi, Godavari, Krishna and Kaveri on the east coast and Narmada and Tapti on the west coast. The seven rivers have a catchment area of 1.83 x 10^6 km^2.

India is one of the 12 mega-biodiversity countries and 25 hotspots of the richest and highly endangered eco-regions of the world (Myers et al. 2000). Review of marine biodiversity of India suggests that the number of faunal and floral species in the Indian waters could be around 13,000 (Venkataraman and Wafar 2005). In fact, the number will be much higher as the available inventory is for commercially important species with very little knowledge on the other phyla. Also in terms of spatial coverage, only two thirds of the marine area have been covered and many areas including the estuaries and islands remain unexplored (Venkataraman and Wafar 2005).

Moreover, Indian coasts host some of the largest and richest shoreline placers. India's placer deposits constitute to about 35% of world ilmenite resources, 10% of rutile, 14.5% of zircon and 71.4% of monazite (Gujar et al. 2001). India meets about 10% of the world requirement of garnet. It is estimated that along the Indian coast the inferred reserves of the placers are 278 mt (ilmenite), 8.19 mt (rutile), 12.29mt (zircon), 4.49 mt (monazite), 53.79mt (silimanite) and 46.11 mt (garnet). While considerable exploitation of placer is being undertaken on Kerala coast, some of the other areas along the west coast are considered a potential site for future mining.

Further, oceans remain in the frontier of intercontinental trade. A large number of countries, including India, are increasingly dependent on the Indian Ocean for their foreign trade, in terms of energy mainly from the Gulf, as well as sea-borne exports. The future is expected to make the sea-lanes of the Indian Ocean highly important not only to India, but also to the littoral states of the Indian Ocean, which are dependent on the ocean for shipping and transportation. Thus, the long coastal belt of India, which is known to be rich in fishery and mineral resource, is, therefore, at high risk of a serious ecological disaster from pollution. Immediate steps, therefore, are required to deal with the consequences.

1.3 The Status of Marine Pollution

1.3.1 Global Scenario

The history of aquatic environmental pollution goes back to the very beginning of human civilization. However, it was not realized until the 1970's and by then, the pollution had reached a threshold level and resulted in adverse consequence to the ecosystem. It was otherwise considered that the world's oceans have an infinite capacity for absorbing the toxic wastes. Pollutants in marine ecosystem are usually derived from human settlements, resource use and interventions. Contaminants of major concerns include persistent organic pollutants, nutrients, oils, radionuclide, heavy metals, pathogens, sediments, litters, debris etc. (Williams 1996). However, most contaminants are interrelated and jeopardize the environment in the same way and scale, regardless of the source of contaminant. Agricultural activities contributed to 50% of the total pollution of surface water (Islam and Tanaka 2004). There has been a huge increase in the use of fertilizers and pesticides worldwide. Pesticides and their residues are reported to be among the most devastating agents for aquatic ecosystems and affect the food chain from the lowest to the top level (Duursma and Marchand 1974; Bryan and Langston 1992). The problem of nitrogen over- enrichment originated with green revolution (in 1970s) and has become a major coastal problem (Howarth et al. 2000; Duda and El-Ashry 2000). Global forecast models of nitrogen export from freshwater basins to coastal waters indicate that there will a 50% world-wide increase in dissolved inorganic nitrogen export by rivers to coastal system from 1990-2050 (rev. Islam and Tanaka 2004).

Sewage effluent includes industrial waste, municipal waste, animal remains, slaughter house waste, faecal matter and many others. It is considered by far the greatest volume of waste discharge to marine environment. It is reported that the annual production of sewage is as high as $1.8x10^8m^3$ for a population of 800,000 (Duursma and Marchand, 1974). Taking the organic matter load to be 20 mg l^{-1} in the sewage, this gives an annual release of $3.6x10m^3$ tons of organic matter. Heavy metals and trace metals are by-products of many industries and finally end as waste in the marine environment. The metals that are considered to be toxic and are of concern have been restricted largely, but not exclusively, to the ten which appear to be most poisonous to marine life. This include, in order of decreasing toxicity- mercury, cadmium, silver, nickel, selenium, lead, copper, chromium, arsenic and zinc (Davies 1978). Metals are non degradable elements occurring naturally in coastal seas. However, they are toxic in their cationic form and in this form they are bioaccumulated in marine organism (Goldberg 1995). Synthetic organic materials (organochlorines, organophosphate, PAHs and organometals) are of growing environmental concern. These xenobiotic compounds are highly toxic and persistent in the environment and biological system. The total amount of dissolved organic matter in the world ocean is about $2x10^{12}$ tons, (volume of world ocean $1.369x10^9$ km^3 multiplied by average concentration of dissolved organic matter of 1.5 mgl^{-1}; Duursma and Marchand 1974).

Plastics contribute to the most significant part of marine litter deposits and solid wastes dumped into aquatic environment. Wace (1995) reported that as many as 600,000 plastic containers worldwide are being dumped daily at sea by shipping. Plastics contributed to >50% of the total stranded and buried litter deposits of the beach all over the world and will be higher in the developing countries due to poor waste disposal management (Islam and Tanaka 2004). The plastics finally get deposited in the ocean floor and interfere with nutrient and gas exchange between sediment and water.

Global sediment load to ocean in the mid-20th century is estimated to be 20,000 million tons per year and 30% of this comes from rivers (Milliman and Syvitski 1992). Aquaculture waste into the sea in Asia, Latin America and Africa are estimated to be about 75-80% depending upon the culture system and degree of management applied (Enell 1995). “Biological pollution” or biological pollutant is the term used to discuss the problems caused by introduced and invasive species (Boudouresque and Verlaque 2002). There are several examples of the damage caused by the introduction of new species in marine and estuarine system (Mills and Holeck 2001).

It can be concluded that the rapid boom in industrialisation along with growing world population have increased the stress on the fragile coastal ecosystem. The world population in 2000 was 6,082,966,429 and estimated to be 9,346,399,468 in 2050 (www.infoplease.com). The increasing human population will put more stress on the marine systems for their day-to-day needs. As a result, the awareness for the need to protect the marine environment from pollution has never been higher. Effective and sustainable management of marine ecosystem has to be initiated for the broader interest of mankind.

1.3.2 Asian Scenario

One quarter of the world's 75 largest cities are situated along the coast of Asian countries (ESCAP 1995). Growth rates of coastal populations are generally higher as a result of migration to coastal urban areas and industrial centres. Most of these large cities and industrial areas are located in highly productive, low lying estuarine areas. Asian countries accounts for 47% of world fisheries production and 87% of the global mariculture production (FAO/RAPA 1994). For insular and archipelagic states, marine resources are the key source of external earnings for development, and marine-based tourism is playing an increasingly important role in the economy of such countries. Most countries in the region rely almost exclusively on fisheries products for dietary protein.

Coastal and marine water pollution is mainly due to direct discharges from rivers, surface run-off and drainage from port areas, domestic and industrial effluent discharges through outfalls and various contaminants from ships. Unfortunately, most of the coastal cities discharge their domestic and industrial wastes directly into the sea without any treatment. The increased use of agro-chemicals also contributed to marine pollution. Fertilizer consumption in the Asia and the Pacific region rose 74 %, from 33.3 million tonnes to 57.8 million tonnes, over the period 1982–92 (ESCAP 1995). Asian rivers account for nearly 50% of the total sediment load (13.5 bt/year) transported by the world's rivers (UNEP 1992). Accidental oil spills are frequently reported in this region (Ingole and Sivadas 2007). Beach tar is also considered a severe problem along the west coast of India, with total deposits of up to 1,000 tonnes a year (GESAMP 1991). Approximately 5 million tonnes of oil enter the Arabian Sea each year and the Bay of Bengal receives some 400,000 tonnes from similar sources (ESCAP 1995). Tourism, tourism encroachment and recreational activities can themselves be a threat to marine and coastal environments. The construction activities which accompany most tourism developments have a range of direct and indirect impacts on coral reefs through infilling, dredging and the resuspension of contaminated silts.

1.3.3 Indian Scenario

India is the world's tenth most industrialized nation and has a population of more than one billion people. The status of marine pollution in India is not much different from the other Asian countries. Table 1.1 gives the amount of different pollutants entering the Indian waters from various sources. Waste management strategies have failed to keep pace with the industrial growth and urbanization. This has resulted in the loss of marine diversity in many parts of the country. Estimates indicate that Mumbai city itself discharges around 2200 MLD of waste to the coastal waters (Zingde and Govindan 2001). Similar is the case with some of the major cities such as Chennai, Kolkata and Visakhapatnam and the industrial areas of Gujarat, Pondicherry and Orissa, where the coastal and estuarine waters remain in degraded condition (Table 1.2). The use of pesticides to enhance agricultural productivity appears to be increasing. India uses 55,000 metric tonnes of pesticides a year of which 25% are thought to end up in the sea (WRI/UNEP/UNEP 1990). The rivers transport about 1194 x 10^6 t of silt to the marine waters every year (Zingde 1989). Study shows that about 70% of the total sea transport is ferried through the India waters (Anon 2003). Oil pollution is a major environmental problem and is important; in particular to the Indian coastline as two main oil tanker routes pass through the Arabian Sea. Moreover, Alang-Sosiya world's largest ship breaking yard is also located along the west coast of India (Gujarat). It certainly puts enormous environmental pressure on the fragile marine ecosystem.

In order to keep a check on coastal pollution, the ministry of Earth Sceinces in close co-operation with the ministry of Environment and Forests initiated surveillance programme "Coastal Ocean Monitoring and Prediction System (COMAPS) in 1991. Twenty-six sites along the Indian coast were identified as hot spots, which are either ecologically sensitive or severely affected by pollution. The main objective of the programme was to assess the health of India's marine environment and indicate areas that need immediate and long-term remedial action. Data on nearly 25 environmental parameters is being collected at about 70 locations with the help of 121 R & D institutions of the country. COMAPS have identified municipal sewage, industrial effluent, aquaculture effluent, port and harbours, ship building and breaking yards, fisheries, coconut husk retting, salt pans, tourism and solid waste dumping as some of the major threat to coastal environment.

From the several types of pollution affecting the fragile coastal ecosystem of the country, the present study focuses on three of the major threats: harbour activities, oil spill and impact of coastal mining.

1.3.3.1 Impact of Harbour Activities

Harbours are protected water bodies that shelter ships from waves and winds. Ports are the land facilities provided alongside a harbour. Harbours can be natural or artificial. Natural harbours result in minimal changes to the environment, while artificial harbours require significant construction to provide the required tranquil conditions for ships.

Commercial shipping activities along the Indian coast have increased immensely in recent years. India currently has 12 major ports and 187 minor ports along its vast coastline. The major ports spread equally on the east and west coast of India. These ports serve as the gateways to India's international trade by sea, handling over 90% of the foreign trade. India ranks among the 20 leading merchant fleets owning countries of the world.

The major ports have handled a total traffic of 423.41 million tonnes during the year 2005-06 and 336.71 million tonnes in the year 2006-07 (Table 1.3). The total vessel traffic includes dry bulk, liquid bulk, break bulk and containers. Liquid and dry bulk cargo constitutes about 83% of the total volume of traffic handled. Container and cargo comprise the remaining 17% (www.meaindia.nic.in).The projected traffic in these ports is considered to be upto 700 MT by the year 2011-12. Therefore, plans to augment the capacities in the major ports to about 1000 MTPA have started to ensure smooth flow of traffic by this period. This would involve capacity addition of about 545 MTPA in the ports during the six years commencing 2006-07. Besides, the average output per ship per day for all major ports taken together has improved from 9240 tonnes in 2004-05 and 9267 tonnes in 2005-06. In addition, over 59,743 mechanised trawlers and about 184196 traditional fishing vehicles operate along the coastal waters of India (Table 1. 4).

Indian ports are indispensable in the development of the country's maritime trade and economy. India's current share in global merchandise trade is around 0.80%. In order to improve efficiency, productivity and quality of services as well as to bring in competitiveness in port services, the port sector has been thrown open to private sector participation. Such private investments are mainly on the Build, Operate and Transfer (BOT) basis. The increasing trade will result in further increase in marine and coastal development in India. This in turn will further affect the sensitive coastal ecosystem of the country.

Pollution is of common occurrence in harbour zones, which severely affect the ecosystem of the area. Dredging is one of the most common anthropogenic disturbances in the harbour carried out for making the channels navigable or during the construction of new structures. Impacts of dredging on benthos can be direct, by displacement or burial (Newell et al. 1998), or indirect via a permanent change in environmental factors such as depth, turbidity, sediment characteristic and water flow patterns (Jones and Candy 1981). Recovery of the seabed and benthos following dredging depends on a varaierty of factors, such as intensity of dredging, and the nature of the benthos. Sites that have been dredged repeatedly over several years may take longer to recover than sites dredged over short periods (Boyd et al. 2005). Furthermore, in the vicinity of the harbour several activities like fishing and industries are carried out which further impact the environment. Besides this, urban effluents, influx fertilizers and pesticides from agricultural areas also flow into the harbour. Therefore, in the harbour the contaminants are not only derived from the shipping activities but also from the river runoff, urban effluent, fishing activities, transportation of ores and mining effluents/rejects.

1.3.3.2 Impact of Oil Pollution

Oil pollution is a major environmental problem and is important, in particular to the Indian coastline as two main oil tanker routes pass through the Arabian Sea. In contrary to the decrease in oil spill globally, the number of tanker spills/accidents has increased along the Indian coast with ≈70% occurring along west coast (Ingole and Sivadas 2007; Sivadas et al. 2008).

Although, currently India has only 0.4% of the world's proven reserves of hydrocarbons, there are indications of large depositions of hydrocarbon and gas hydrates in the deeper continental margin (http://planningcommission. nic.in). At present, India's main oil reserves are located in the Mumbai High, Upper Assam, Cambay, Krishna-Godavari, and Cauvery basins. The offshore Mumbai High field is by far India's largest oil producing field. Normal output at Mumbai High is around 275,000 barrels per day (bbl/d). India's average oil production level (total liquids) for 2005 was 837,000 bbl/d, of which 632,000 bbl/d was crude oil (www.eoearth.org/article/Energy_profile). India had net oil imports of nearly 1.7 million bbl/d in 2005. The demand for oil is increasing faster than the addition to the proven reserves of the country as a result India imports around 70% of its oil. Similarly, some of the states in South-East Asia, East Asia, Japan and China are heavily dependent on the import of oil from West Asia.

In the past fifty years, oil pollution has become a major problem in the coastal zone. Drilling, transport, and burning have all led to addition of oil to marine environments. The greatest toxic damage is caused by spills of lighter oils, particularly confined to smaller areas. Surface currents, controlled by local winds, tidal forcing, surface waves, eddy, and large-scale pressure gradients, can push contaminated off shore water directly into the shore (Barrick et al. 1985; Quigley 1996). Lighter oil reaches the shore quickly and is more toxic to shore life than oil that has weathered at sea for several days before stranding. Lighter oils are more likely to penetrate the sediments and affect infauna (Ansari and Ingole 2002). On the other hand, heavy oils form stable oil in water emulsion that are highly persistent and fuel to their greater proportion of non-volatile components and high viscosity have the potential to travel long distances from the original spill causing wide spread contamination of coastline.

Immediately after an oil spill, due to the blocking of air-sea exchange, the phytoplankton population is severely depleted. Production of zooplankton is retarded as these will ingest more oil in their guts due to the availability of excess oil and which, they are known to secrete when the source of oil is absent. McIntyre (1982) considers that fisheries on the continental shelves are at greater risk than those offshore, and that effects on shallow coastal intertidal areas may last for years. Seabirds are the most conspicuous marine organisms and are used as monitors of the marine environment (Montevecchi 2001) and of the incidence of oil pollution for decades (Furness and

Camphuysen 1997). Sea mammals with restricted coastal distributions and ones that breed on shorelines are more likely to encounter oil than wide-ranging species moving quickly through the area.

The vulnerability of coastal areas to oil pollution is generally recognized, and it is essential that such areas are protected to ensure the health of aquatic organisms. Contaminants can concentrate in pools, end up on the beach, and cover intertidal zones where many organisms live. Oil concentrating in the water after an oil spill has been shown to have adverse affects on intertidal communities (Newey 1995). The most immediate effect of high levels of oil on intertidal organisms would be narcosis and the inability of organisms to adhere to the substrate (Newey 1995).

1.3.3.3: Impact of mining

The world demand for mineral raw material is expected to increase more than threefold with increase in population and the industrialization. Though, India's mineral resources generally appear to be sufficient to meet the projected demand, resources of some metals may be insufficient on land (Nath et al 2004). Therefore, further discoveries and investments are needed to meet the rising demands. In a quest to search for new areas, man has viewed the ocean as a last frontier for raw materials. The oceans contain vast quantities of minerals and metals. Among the mineral deposit, placer deposits are attracting the attention of industrialists in view of rich concentration of minerals like zircon, garnet, ilemnite and monazite in them. Placer minerals accounts for 34% of diamond and 69% of gold production of the world (Sutherland 1985). They are also major sources of other minerals such as platinum, tin, cassiterite (Garnett and Basette 2005). However, the focus of large scale placer mining is for diamonds, zircon and rutile / ilmenite (Garnett and Basette 2005).

The environmental impacts of mining and mining rejects vary with the type of mineral and the kind of mine. However, mining is inherently a destructive activity involving the taking of a non-renewable resource. Some environmental damage is inevitable in any mine. Removal of sediment from the coastal region affects the near shore bathymetry, which in turn affects the near shore processes. Offshore mining may possibly disturb the unique and sensitive coastal habitats (Diaz et al. 2004). Sand shoals tend to be focal points for various fisheries, both recreational and commercial. Altering the physical characters of the areas (i.e. grain size, morphology wave and current regime) would be detrimental for the marine species.

1.4 Significance of benthos in the marine ecosystem

1.4.1 Benthos

Marine sediments cover most of the ocean bottom, and the organisms that reside in these sediments therefore constitute tha largest faunal assemblages on Earth. The organisms, which live in, on, or are occasionally associated with the bottom are known as benthic organisms and collectively form the "Benthos". Benthic communities in general, are sessile and slow moving in nature. Among the benthic animals, almost 75% live on the firm substrates (rocks, corals, etc.), 20% on sandy/muddy bottoms and only 5% are planktonic (Thorson 1957). Many benthic animals within the sediment perform periodic vertical migration. The distribution of benthic organisms varies inversely with water depth. Benthos are defined on the basis of their position in the sediment relative to the surface and on their size. Animals that live on top of sediments, rocks and plants are called epifauna. They can be sessile or mobile. Infauna are animals of any size which live within the sediment, moving freely between interstitial spaces. Separation with respect to size of benthic fauna is done using sieves: microfauna are retained on 1-100µm sieve, meiofauna on 63µm and macrofauna on 0.5mm sieve (Rees 1940; Mare 1942; McIntyre 1969; Rees 1984; Bachelet 1990; Schlacher and Woolridge 1996). Megafauna are those larger than macrofauna. Benthic fauna also classified on their ecological status as interstitial, eulittoral, sublittoral and abyssal.

1.4.2 Benthos and the marine food web

Benthos is the key component of the marine ecosystem. Their ability to adapt in various habitats makes them important as food for large organism, especially the demersal fishes (Takai et al 2002; Ingole et al 2006), which contributes to 30-50% of the total fishery potential of the area. The sediment organic matter from the water column is effectively consumed and converted into invertebrate benthic biomass, dissolved organic matter and inorganic nutrients by benthic organism. Therefore, they are also called as conveyor belt organisms. The nutrients released from the sediment due to bacterial degradation of organic matter diffuse and disperse rapidly into the overlying water and influence the primary production, which in turn triggers zooplankton production in the marine environment. The benthic ecosystem of coral reefs, mangroves, intertidal beach and mudflats serves as a good feeding, breeding, spawning, and nursery grounds for many marine organisms of economical importance, variety of migratory and resident birds, sea mammals and reptiles.

1.4.3 Benthos as 'bioturbators'

The sediment reworking by the benthic organisms during their movements and feeding activities is known as "bioturbation" or "biological bulldozing". It helps to condition the sediments for sheltering meiofauna and microfauna and as a stimulant of nutrient regeneration. Bioturbation increases oxygenation and mineralization (Kristensen et al. 1985; Tamaki and Ingole 1993), and alters the sediment geochemistry (Aller et al. 1983; Marinelli 1992). Bioturbation enhances the exchange of important constituents such as carbon, nitrogen, sulphur, phosphate and silica which increases the productivity in the sediment and water column (Marinelli 1992; Ingole et al. 2005). Solan et al (2004) showed the importance of bioturbation in the marine system. The numerical model showed that species extinction reduced the depth of bioturbated sediment, which can alter the flux of energy and matter that are vital to the global persistence of marine communities (Solan et al. 2004).

1.4.4 Benthos as bioindicators

Blandin (1986) defined the term bioindicator as an organism or group of organisms, which allow characterizing the state of an ecosystem based on biochemical, cytological, physiological, ethological or ecological variables.

Benthic macro-invertebrates are good indicators for determining changes in the environmental status and trends because numerous studies have demonstrated that benthos responds predictably to many kinds of natural and anthropogenic stress (Pearson and Rosenberg 1978; Wilson and Jeffrey 1994; Ingole et al. 2005; 2006). Many characteristics of benthic assemblages make them useful indicators (Bilvard 1987), the most important of which are related to their exposure to stress and the diversity of their response. Exposure to short-term disturbances such as hypoxia is typically greatest in near bottom waters and anthropogenic contaminants generally accumulate in sediments where benthos lives. Long-term disturbances such as accumulation of contaminants in sediment affect the population and the community dynamics of benthic macro invertebrates (Rosenberg 1977; Rygg 1985). Benthic fauna generally have limited mobility and cannot avoid these adverse conditions (Wass 1967). This immobility is advantageous in environmental assessments because, unlike most pelagic fauna, benthic assemblages reflect local environmental conditions (Gray 1979).

Pocklington et al (1992) demonstrated that some polychaete species are useful as bioindicator of the polluted areas. Many species of *Capitella* sp. are known for their tolerance to anoxic conditions associated with high organic enrichment. Amphipoda is a sensitive environmental indicator due to their ecological importance, numerical abundance and sensitivity to a variety of toxicants and pollutants (Hart and Fuller 1979). Amphipods have been found to be more sensitive than the other species of invertebrates to a variety of contaminants (Swartz et al. 1985). Furthermore, amphipods have been documented to show the response to other parameters including dredging, shoreline alteration, fishing practices, salinity and dissolved oxygen (Widdowson 1971).

Benthic macrofauna are among the most common organisms used in biological monitoring for the following reasons -

- Majority of the species are sedentary.
- High species richness with a variety of life history patterns and tolerances to habitat disturbances
- Their responses integrate water and sediment quality changes
- Relatively long life span of some species
- Key elements in the food web of aquatic systems.
- Affect chemical fluxes between sediments and water column

1.5 Literature Review

The United Nations Convention on the Law of the Sea defined pollution as "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and the marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for uses of the sea water and reduction of amenities" .

Williams (1996) criticized the division of pollution into categories and said that there is only "one pollution" because every pollutant, whether in the air, or on land, tends to end up in the ocean. Unfortunately, the pollution problem as described by Williams (1996) is characterized by interconnectedness, complicated interactions, uncertainty, conflicts and constraints, making it difficult to control the problem. Moreover, the scientific knowledge on marine pollution is patchy which is identified as the major constraint in introducing effective management strategies for its control. Quality assessment of marine ecosystem can be effectively carried out by studying the sedimentary habitat and the associated fauna, as most of the ecological impact and pollution eventually will end up on the seabed (Rosenberg et al. 2004).

Classification of aquatic system into different degrees of pollution was first developed for freshwater in the saprobic system (Kolwitz and Marsson 1909). Reish (1955) was the pioneer in classifying the marine benthic system by using the pollution tolerant polychaetes and later used by others (Rosenberg et al. 1975; Bellan 1985). Based on these studies, relation between magnitude of disturbance and temporal or spatial changes in the benthic faunal composition were summarized and formulated in the Pearson and Rosenberg (1978) model. The benthic faunal successional changes in this model were depicted as a response to organic enrichment and oxygen deficiency, but was later also shown to apply for physical disturbance (Boesch and Rosenberg 1981; Rhoads and Germano 1986) and to organic enrichment in association with contaminants (Swartz et al. 1985). This model seems to have universal application for most disturbed, sub-littoral, soft bottom habitats (e.g Heip 1995).

Effects of perturbation include changes in diversity, biomass, abundance of stress tolerant or sensitive benthic species and the trophic or functional structure of the benthic community (Pearson and Rosenberg 1978; Warwick 1986; Warwick and Clarke 1994; Kaiser et al. 2000; Grall and Chauvaud 2002). Scientists have used characters of benthos to detect the health of marine system (Gray and Mirza 1979; Gray 1981; Pearson et al. 1983; Ingole et al. 2008). Warwick (1986) proposed that species ranked in order according to their abundance and biomass may be useful for determining the status of pollution. Different types of diversity indices have been widely used in ecology for the assessment of environmental quality; a high index value will indicate healthy conditions and low index value bad conditions. Recent studies developed multimetric indices to get a more reliable tool for the assessment of ecological quality in a benthic ecosystem. These indices based on the model of Pearson and Rosenberg (1978) which used indicator species or ecological groups of species according to their sensitivity to stress. Some of the recent multimetric indices include Benthic Index (BI; Grall and Glémarec 1997),. Azti Marine Biotic Index (AMBI; Borja et al. 2000) and the biotic index (BENTIX; Simboura and Zenetos 2002). Others have used a combination of univariate and multimetric indices such as the benthic index of biotic integrity (B-IBI) (Weisberg et al. 1997) and the Ecological Quality Ratio (EQR; Borja et al. 2003a). However, most of these indices have been formulated to differentiate between anthropogenically disturbed sites from undisturbed reference sites (Van Dolah et al. 1999; Borja et al. 2003b; Muxika et al. 2005), but univariate as well a multimetric indices respond to any disturbances, natural or man made (Wilson and Jefferey 1994). Therefore, for the evaluation of general ecological quality status of marine environment as well as for the indication of reference condition, the “natural” variability of the indices on temporal and spatial scales has to be assessed and taken in account (Vincent et al. 2002).

Others have used species ratio to assess the marine system. Bellan (1980) used for the first time Annelid Index of Pollution based on the ratio of summed dominance of “Pollution sentinel species to that of the pure water sentinel species”. Gómez Gesteira and Dauvin (2000) tested the polychaetes /crustaceans, opportunistic polychaetes /crustaceans, and polychaetes /amphipods ratio for determining the impact of oil contamination on soft-bottom communities and suggested that opportunistic polychaetes/amphipod ratio to be highly efficient. Dauvin and Ruellet (2007) modified the opportunistic polychaetes/amphipod ratio to benthic opportunistic polychaetes amphipods index (BOPA) and consider it appropriate for use in the poorest communities whose total number of individuals exceeds 20 individual. However, an important theme that emerged during the workshop of Benthic Indicators Group (BIG) of the Intergovernmental Oceanographic Committee (IOC), was the recognition that wide suite of tools, methods and models would be best for such purposes rather than any one single indicator (Anon 2005).

A review conducted on the work carried out on the Indian estuaries showed that about 1182 research papers have been published on various aspects of Indian estuaries (Anon 2002). Among these, 15.40% of the papers dealt with estuarine fauna followed by chemical aspects (13.70%). The papers on fisheries, ecology, hydrobiology, plankton, pollution and geology accounted for 13%, 12.69%, 9.98%, 9.64%, 9.22%, 6.26%, respectively. The least studied area is microbiology (4.48%), management (3.3%) and flora (2.28 %).

Seshappa (1953) and Kurian (1953) who studied Madras, Malabar and Travancore coasts have carried out the first studies on the benthic fauna of India. Studies on benthic fauna of the west coast of India are many; however, most of them are regional studies. Neyman (1969) divided the West Indian Ocean shelf into SW and NW regions on the basis of epibenthic biomass, and suggests that the boundary of this region lies in the vicinity of Goa (lat. 15°S). Elizarov (1968) suggested that the high benthic biomass observed south of 19°N in the Arabian Sea was correlated to the inflow of low salinity equatorial waters causing a strong stratification and was confirmed by Harkantra et al (1980) and Parulekar et al (1982). Ingole et al. (2002) studied the macrobenthic communities of the Dabhol and concluded that the coastal waters to be to highly productive and favours breeding and feeding of commercially important prawn and crab species. Similar studies have been carried out along the Indian coasts (Ganapati and Lakshmana Rao 1959; Radhakrishnan and Ganapati 1969; Kurian 1971; Damodaran 1973; Parulekar and Wagh 1975; Ansari et al. 1977; Harkantra et al. 1980, 1982; Harkantra and Parulekar 1987; Raman and Adiseshasai 1989; Devi et al. 1996; Raut et al. 2005; Ingole 2007).

Studies on the estuaries of Goa dates back to 1970s. However, the study of Parulekar et al (1982) is the first detailed account of the macrobenthic fauna of the Mandovi-Zuari estuarine complex. They recorded 111 macrobenthic species in the area and the polychaetes dominated the macrofaunal community.

The general aspects of pollution-induced changes in coastal waters are many (Zingde et al. 1979; Qasim and Sen Gupta 1988; Ramaiah and Chandramohan 1993; Satyanarayana and Sen Gupta 1996; De Sousa 1999; Balachandran et al. 2006; Desa et al. 2005; Rejemon et al. 2008 and others). However research on the impact of pollution on the marine benthos and its use as environmental indicator, are very few from the Indian waters. Dwivedi and Desai (1972) reported that the coastal water off Mumbai were unsuitable for fishery due to high toxicity of the waters. A similar condition was observed in the coastal waters of Versova (Varshney et al. 1988) and off Mahim (Varshney 1995). Mathew (1995) reported the dominance of polychaete species indicator of environmental stress in the inner creek of Thane and Bassein. Further, they reported that the area was unfit for any kind of aquaculture practice and harvesting of economically important species (Varshney and Govindan 1995). Meiofauna dominate in terms of abundance and biomass in estuaries of South Gujarat and the benthos were heavily affected in areas influenced by industrial pollution (Govindan et al. 1983). The cosmopolitan opportunistic polychaete, *Capitella capitata* was dominant in the Cochin backwaters receiving effluents from various Industries (Devi and Venugopal 1989; Devi et al. 1991; Balachandran et al. 2006). Abundance and diversity of benthic polychaetes were higher at sites receiving effluents from domestic sewage and waste from nearby fish landing jetty (Ansari et al. 1986). Gopalakrishnan and Nair (1998) studied the impact of industrialisation along the Mangalore coast and reported the dominance of molluscs and polychaetes. Further, they did not notice significant impact of industrialization on the macrobenthic fauna. However, Harkantra and Rodrigues (2003) using univariate and multivariate techniques reported the Mormugao harbor to be highly polluted and identified as a pollution "hot spot" along the west coast of India.

A comparison of two clam bed sites in the Mandovi River and Cumbarjua canal showed a decline by 70% and was linked to increased mining activities in the area (Parulekar et al. 1986). Moreover, the benthic fauna showed low species diversity and was dominated by tolerant species. Ansari and Abidi (1993) also found that mining rejects and disturbance caused by mining activities decrease the macrobenthic standing crop by >40% and species diversity by 50% in the estuaries of Goa. Sheeba et al (2004) reported the low macrofaunal abundance in the dredged and disposal site of Cochin waters.

Studies on the effect of oil pollution along the Indian coast are limited. Nair et al (1972) studied the tar ball distribution on some of the sandy beaches along the central west coast of India. Dwivedi and Parulekar (1974) studied the intensity of tar ball disposition and their possible origin along the West and East coast of India. Qasim (1975) made a general review of tar ball deposition along the beaches of west and east coast of India. Sen Gupta et al (1980) studied dissolved petroleum hydrocarbons in some regions of Northern Indian Ocean. Ramamurthy (1982) reported the oil pollution in the west coast of India off Arabian Sea from 1971 to 1980. The west coast of India (Arabian Sea) is more polluted compared to the east coast because of the heavy transportation of crude oil by tankers from the Middle East oil fields to the South East Asia and Far East (Ramamurthy and Sreenivasan 1983). Similarly, the deposition of tarballs on the west coast beaches was found to be on higher side when compared to east coast of India (Ramamurthy and Sreenivasan 1983).

Large spills caused by '*Cosmos Pioneer*' disaster in North west coast of India and '*Trans Huron*' in south west coast of India resulted in heavy kill of organisms and prevented the resettlement of the sediments by the original fauna (Nammalvar and Ramamurthy 1976). Fondekar et al (1980) studied the distribution of PHC in coastal waters of Goa and reported the average PHC value in water and sediment to be 30.9 $\mu g\ l^{-1}$ and 7.1 $\mu g\ g^{-1}$ dry weight, respectively. PHC deposition in Murud and Rajpuri area from rupture of feeder pipeline in 1993 did not show drastic change in the marine community and normal condition was observed within a year (Gajbhiye et al. 1995). The short- and long-term effects of a fuel oil spill from "*MV Sea Transporter*" on meiofauna were investigated by Ansari and Ingole (2002). A significant reduction in the absolute abundance of meiofauna was observed immediately after spillage, particularly at Sinquerim beach, the site of spillage. The ecotoxicological effects of oil spill from the grounded ore carrier "*MV River Princess*" on the intertidal benthic organism of Sinquerim-Candolim was investigated by Ingole et al (2006). The result of the study suggests that the vessel not only affected the benthic community and may have long-term impact on the local fishery, but also affected the beach morphology. Oil spill from unknown source off Goa in August 2005 have been studied by Ingole et al (2005; www.nio.org). They reported heavy mortality of beach communities immediately after the occurrence of oil slick.

1.6 Objectives of the proposed study

Review of published literature revealed that the Indian estuaries are affected by various anthropogenic activities. Consequently, the long coastal belt of India, harbouring rich biological diversity and other resources, is at high risk of a serious ecological disaster. Immediate steps therefore, are required to deal with the consequences.

Being the primary consumer, benthic macroinvertebrates play very important role in the benthic food chain. Some dominant macrobenthic forms such as polychaetes are considered as the convener belt organisms in processing the organic matter. Even though information on the macrobenthic communities of the Indian estuaries are very well documented in literature, however, there are many aspects where knowledge or data are insufficient for understanding the variability caused by natural and/or anthropogenic disturbances.

Many aspects have been identified where there is either limited data or contradictory knowledge base and therefore require further research. Although Mormugao port play an important role in the economy of the country, studies dealing with effect of the harbour activities on the marine benthic communities are lacking. Earlier data on the marcofaunal community of the harbour is based on a single sampling that does not consider the spatio-temporal variability. Environmental sampling to detect and measure stresses is made extremely difficult by natural spatial and temporal variations. A stress would therefore only be indicated if there were some changes in response to a disturbance that is greater than or in some other way different from natural changes. Therefore, there is the need to measure temporal change so that any unnatural change can be identified in comparison to it. The study attempted to provide comprehensive information on the spatio-temporal variability of macrobenthic community of the major ports of India, an increasingly vulnerable region for invasions. Such investigations will also help to study the impact of dredging in structuring the macrobenthic community of the area.

Since coastal stretch between Goa and Ratnagiri are considered as potential site for placer mining, the present thesis also addresses the impact of mining on the macrobenthic community. Kalbadevi Bay in Ratnagiri is identified to have rich deposit of ilmenite. A prerequisite for any attempt to understanding the impact of human interference on the ecosystem is knowledge of the current species distribution and abundance. Without adequate knowledge on the biodiversity of any geographical area, management plans to prevent, control, and minimize their economic, and environmental impacts are inadequate. Thus, in addition to providing the baseline information, an experimental disturbance was conducted. The experimental design will allow for the reliable interpretation of impact of mining and for better management of the area. Literature review revealed the increase of incidents of oil spill in the Indian waters. Therefore, an attempt was also made to review the impact of such spills on the marine ecosystem.

Therefore, the study was conducted with the following broad objectives:

- Structuring of macrobenthic community in the intertidal and sub tidal areas.
- Impact of physical disturbance (dredging and mining) on the macrobenthic community.
- Recolonisation of macrofauna after physical disturbance.
- Impact of oil spills on macrobenthic community.
- Ecology of *Umbonium vestiarium.*

Table 1.1
Type and quantum of pollutants released into the coastal ecosystem of India*

1.	Sediments	1600 million tones
2.	Industrial effluents	50×10^6 m^3
3.	Sewage - largely untreated	0.41×10^9 m^3
4.	Garbage and other solids	34×10^6 tonnes
5.	Fertilizer - residue	5×10^6 tonnes
6.	Synthetic detergents - residue	1,30,000 tonnes
7.	Pesticides - residue	65, 000 tonnes
8.	Petroleum hydrocarbons (Tar balls residue)	3,500 tonnes
9.	Mining rejects, dredged spoils & sand extractions	0.2×10^6 tonnes

*Source: www.teriin.org/teri-wr/coastin/papers/paper2.htm

Table 1.2
Quantities and waste generation rates in some coastal cities *

S.No.	Name of City	Population	Area (Sq km)	Waste Quantity (Tons/day)	Waste Generation (kg $c^{-1}day^{-1}$)
1	Kavaratti	10119	4	3	0.30
2	Daman	35770	7	15	0.42
3	Panaji	59066	69	32	0.54
4	Port Blair	99984	18	76	0.76
5	Pondicherry	220865	19	130	0.59
6	Kochi	595575	98	400	0.67
7	Thiruvananthapuram	744983	142	171	0.23
8	Vishakhapatnam	982904	110	584	0.59
9	Chennai	4343645	174	3036	0.62
10	Kolkata	4572876	187	2653	0.58
11	Greater Mumbai	11978450	437	5320	0.45
	TOTAL	30128210	1734	14782	07
	Annual input			539540	2555

*Source: Central Pollution Control Board, 2005

Table 1.3
Traffic Handled at major ports during April to March 2006 and 2007*

				FERTILIZER		COAL		CONTAINER		OTHER	TOTAL	% VAR.
PORT	TRAFFIC	P.O.L	Iron ore	FIN.	RAW	THERMAL	COKING	TONNAGE	TEUs	CARGO		2005-06
KOLKATA												
Kolkata Dock System	2007	5181	224	-	15	-	-	4005	240	3171	12596	
	2006	4934	101	-	-	-	-	3234	203	2537	10806	16.56
Haldia Dock Complex	2007	18074	8317	420	387	2443	5427	1894	110	5492	42454	
	2006	17689	7939	324	508	3408	5371	1911	110	5187	42337	0.28
Total: Kolkata	2007	23255	8541	420	402	2443	5427	5899	350	8663	55050	
	2006	22623	8040	324	508	3408	5371	5145	313	7724	53143	3.59
Paradip	2007	1376	11880	89	2856	12474	4274	31	2	5537	38517	
	2006	910	10273	-	1568	12529	3758	45	4	4026	33109	16.33
Visakhapatnam	2007	18179	14718	2618	831	2406	6756	800	50	10078	56386	
	2006	16941	16171	2295	891	2740	7068	630	47	9065	55801	1.05
Ennore	2007	189	1723	-	-	8802	-	-	-	-	10714	
	2006	244	537	-	-	8387	-	-	-	-	9168	16.86
Chennai	2007	12939	10480	651	363	2181	1390	14166	798	11244	53414	
	2006	13113	9527	701	371	1914	1183	11757	735	8682	47248	13.05
Tuticorin	2007	738	-	678	697	5608	-	4013	377	6267	18001	
	2006	774	-	484	958	6146	-	3428	321	5349	17139	5.03
Cochin	2007	10476	-	79	525	219	-	3005	227	1010	15314	
	2006	9641	-	81	598	199	-	2488	203	880	13887	10.28
New Mangalore	2007	21868	6248	972	23	-	1046	265	17	1620	32042	
	2006	22392	9307	662	-	-	513	149	10	1428	34451	-6.99
Mormugao	2007	786	26740	226	-	350	3605	127	12	2407	34241	
	2006	833	25314	228	-	378	2895	105	9	1935	31688	8.06
Mumbai	2007	32171	-	136	327	2532	-	1580	128	15618	52364	
	2006	27781	-	171	424	1844	-	2145	156	11825	44190	18.50
J.N.P.T.	2007	2658	-	-	-	-	-	40812	3298	1348	44818	
	2006	2545	-	-	-	-	-	33777	2667	1514	37836	18.45
Kandla	2007	29711	233	2049	172	293	411	2778	177	17335	52982	
	2006	24290	2	1678	252	113	313	2311	148	16948	45907	15.41
All Ports	2007	154346	80563	7918	6196	37308	22909	73476	5437	81127	463843	
	2006	142087	79171	6624	5570	37658	21101	61980	4613	69376	423567	9.51
% Variation from previous year		8.63	1.76	19.54	11.24	-0.93	8.57	18.55	17.85	16.94	9.51	

*Source : Indian Ports Association (http://business.gov.in/Industry_services/ports)

Table 1. 4
Total number of fishing vessels (state-wise) operating along the coastal waters of India*

State/UT	Traditional crafts	Motorised traditional crafts	Mechanised boats	Total
Andhra Pradesh	24386	14112	2541	41039
Goa	532	932	1087	2551
Gujarat	3729	7376	13047	24152
Karnataka	7577	3705	4373	15655
Kerala	9522	14151	5504	29177
Maharashtra	7073	3382	13053	23508
Orissa	15444	4719	3577	23740
Tamil Nadu	24231	22478	7711	54420
West Bengal	10041	1776	6829	18646
Andaman & Nicobar	1837	781	165	2783
Daman & Diu	211	654	562	1427
Lakshadweep	1341	376	667	2384
Pondicherry	1524	2306	627	4457
Total	107448	76748	59743	243939

*Source: Marine Census, 2005, Fishery Survey of India - Govt. of India.

Chapter 2

Environmental parameters in Mormugao harbour

2.1 Introduction

The seas are major trade routes and in recent years, there has been a significant increase in maritime trade. To meet the increasing demand of the population and industries, new ports are constructed and the existing ones are being expanded. It would definitely influence the commercial and economic growth of the country. Maritime development especially, along the estuaries and sensitive coastal areas can have catastrophic long-term impact on the marine environment. Harbour activities cause an overall negative impact on not only the marine environment but also cause considerable pollution to air and land (Darbra et al. 2005). However, the degree of impact on environment will depend on the geography, hydrology, geology, and ecology, type of shipping, industrialization and urbanization of the area.

The levels of pollution along the Indian coast are increasing and the west coast perhaps, is more polluted compared to the east coast (Sengupta et al. 1989; Zingde 2002; Ingole 2004). This may be because six major harbours are located along the west coast resulting in higher movement of transport vessels. Handling losses at oil terminals in the east and west coast of India in the recent years also show phenomenal increase. Further, the west coast of India is recognized to have rich biodiversity (Ingole, 2004; Venkatraman and Wafar 2005) and contributes to >70% of the marine capture fishery (Somavanshi 2003). Thus, the west coast of India is under a persistent threat from increasing maritime activities.

The Mormugao Port

Mormugao Port, with a fine natural harbor, is one of the oldest major ports on the west coast of India. At the time of its commissioning in 1888, the Mormugao Port comprised of 3 berths along with a breakwater having a length of 358 meters. As the infrastructures slowly kept growing, new berths (4 and 5) were built and the breakwater was extended to its present length of 522.40 meters (www.mormugaoport.gov.in). A mole of 270 meters was added later.

History of Mormugao Port

With the emergence of mining as a major industry in Goa, the Portuguese Government developed a master plan for the development of Mormugao Port as an iron ore terminal. A berth fitted with mechanical ore loading plants was dedicated for this and was financed by various iron ore exporters. In accordance with this, in 1959 Asia's very first mechanical ore handling plant was commissioned at berth No.6, with a capacity of 1000 tph.

Development in the port after liberation

The declaration of Mormugao as a major port in 1964 was a milestone in the annals of its history as it joined the ranks of the country's ten major ports. In 1965, a perspective plan was drawn up, to be competitive in the international arena by reducing the transportation cost. As a first step in that direction, a 20-year perspective plan for the port development was prepared. As a follow-up on the report a mechanized ore handling facility for receiving, stockpiling, reclaiming, weighing, sampling, and ship-loading of 12 million tones of iron ore annually was installed and commissioned in 1979. Barge unloaders and rail wagon tippers were provided for quicker and more efficient handling of incoming ore.

A number of developmental projects were implemented under the various ***Five Year Plans***. Consequently, a dedicated mineral oil berth, berth No. 8 was constructed in 1976. Two multi-purpose general cargo berths berth No.10 and No. 11 having draft of 11.00 mts and 12.50 mts were constructed and commissioned in 1985 and 1994 respectively to meet the increasing cargo traffic. The old berths no. 1 to 3 were leased out to Western India Shipyard Ltd, for installing a modern ship repair facility, which was commissioned in 1995. In 1997, the metre gauge railway of the port linking to the South Central Railway was converted to broad gauge.

Mormugao harbour is the premier iron ore exporting port of India with an annual throughput of around 23 million tonnes of iron ore traffic. It accounts for ≈ 39% of country's iron ore export and ranks within the first ten leading iron ore exporting ports of the world. Though, iron ore is the predominant cargo, there has been a steady increase in liquid bulk and general cargo traffic ever since it's joining in the ranks of the major ports of India. Since 1992, there has been a regular container service from the port and the container traffic has registered a rapid growth within a short span of time. During the financial year 2007, the port handled traffic of 34241 tonnes, which is 7% of the total traffic of 463843 tonnes handled by all the twelve major ports of India (Table 1.5). With the saturation of Mumbai and Jawaharlal Nehru Ports, Mormugao port by commanding a strategic position on the coastline of the region, and offering a much quicker turn around time, is poised to become a major transit point for trade in goods originating from or destined for Central and North Central India. In the likely eventuality of free port status being granted to Mormugao, the role of the port will be further enhanced in the years to come.

Historically, harbours worldwide have been assessed for pollution status. Traditionally, harbours have poor water quality caused by internal stagnant regions within the harbour (Falconer 1980; Estacio et al. 1997). The harbours are characterized by anoxic condition, high levels of pollutants and low to complete defaunation of the area (Reish and Gerling 1997).

The present section deals with the impact of the harbour activities on the coastal ecosystem and the objective of this study are:

- Spatial and temporal variation in the environmental parameters
- Spatio-temporal variation of the macrofauna and evaluation of environmental quality of Mormugao harbour
- Impact of dredging on macrobenthic community.
- Comparative study of the macrobenthic community of three harbours along the west coast of India.

2.2 Materials and Methods

2.2.1 Study Area

Mormugao harbour (Lat.15°25' N and Long.73° 47'E) is located on the southern bank of the Zuari river mouth (Fig 2.1a-c). There exists three quay berth, one deep-drafted oil berth, one specialised mechanical ore berth and two multipurpose general cargo berths. A breakwater of 522.40 meters long protects the harbour from the SW monsoon. The harbour is dominated by periodic tidal exchange of oceanic and estuarine water (Cherian et al. 1974; Shetye 2007) with strong bottom currents (1.5 m s^{-1}). The 10 km stretch upstream from the mouth of the Zuari estuary, known as the Mormugao Bay, is approximately 5 km wide.

2.2.2 Sampling and Analysis

Sampling for sediment and water column study was carried out at seven predetermined subtidal locations (Fig.2.1 d; Table 2.1a) from September 2003- July 2004. At each station, sediment sample was taken for the analysis of chlorophyll *a* and organic carbon. Chl *a* was analysed by acetone extraction method (Holm-Hansen 1978) and organic carbon was analyzed by wet oxidation method (El Wakeel and Riley 1957). Water parameters (Dissolved oxygen: DO; biological oxygen demand: BOD; nutrients, chl *a*, petroleum hydrocarbon: PHC, pH, temperature, salinity, and water Cd, Pb and Hg) and sediment metals (Cd, Pb, Hg) studied concurrently (Table 2.1b) and reported earlier (Anon 2004a) were used for correlation analysis

2.2.3 Data Analysis

The environmental data was initially processed using Microsoft Excel. In order to distinguish the variations of each parameter for a given season, the data was further divided into three seasons i.e Monsoon (June-Sept), post monsoon (October-January) and pre monsoon (February-May). Analysis of Variance (ANOVA) was used to determine the overall significance of differences among samples for the variables and a post hoc Tukey's test for multiple comparisons between groups of samples assembled according to the significant factors. Correlation was carried out, in order to relate the environmental parameters (Statistica 6). The PCA of the parameters was performed using Primer 6.

2.3 Results

2.3.1 Water parameters

Summary of environmental parameter is given in table 2.2 - 2.3. Annual changes in water temperature were typical of tropical estuary. Surface and bottom water temperature showed significant variation between seasons ($p<0.001$; Table 2.4). The bottom water temperature values ranged from 27°C (monsoon) and highest during pre monsoon (30.3°C). Tukey's post hoc test for differences showed that the temperature during monsoon was significantly low. The surface water salinity increased from 21.5 psu during monsoon to 34.2 psu in pre monsoon and seasonal fluctuation was statistically significant ($p<0.001$). Similarly, the bottom water salinity ranged from 29.6-33.6 psu observed during the same seasons. Spatio-temporal and season x station variation in bottom water salinity was statistically significant ($p<0.001$; Table 2.4; Fig.2.2 b and b'). Tukeys post hoc test for differences showed salinity at stn 2-4 were significantly high. Surface water pH ranged from 7.9 – 8.1 recorded at stn 1 and 7, respectively (Table 2.2). The surface water pH was stable over the study period with mean values varying from 8- 8.1 during monsoon and post monsoon respectively. pH of the bottom water was high during the post monsoon (8.1) and low during the monsoon (7.8). The seasonal variation in pH was statistically significant ($p<0.05$). However, pH values did not vary between the stations (7.9-8). A significant difference was noted between surface and bottom water pH values ($p<0.05$). Figure 2.2 a-c represents the seasonal variation of salinity, temperature and pH at the seven stations.

The surface water PO_4 ranged from 0.79- 1.4 μ mol l^{-1} recorded during post monsoon and monsoon, respectively. Stn 7, recorded highest PO_4 values (1.7 μ mol l^{-1}) and lowest value of 0.86μ mol l^{-1} was at stn 2. Highest PO_4 value in the bottom water was observed at stn 7 (1.7 μ mol l^{-1}) and lowest at stn 2 (1.1 μ mol l^{-1}). Seasonally, bottom water PO_4 was low during pre-monsoon (0.97μ mol l^{-1}) and high during the monsoon (1.9 μ mol l^{-1}). Surface and bottom concentration of PO_4 showed a significant seasonal variation ($p<0.001$). Mean NO_2 in the surface water was highest during pre monsoon (0.69 μ mol l^{-1}) and lowest value of 0.1 μ mol l^{-1} was recorded in monsoon. Lowest value for NO_2 in surface water was at stn 1 (0.3 μ mol l^{-1}) and at stn 4 (0.51μ mol l^{-1}) had the highest value. Bottom water NO_2 showed a different trend to that of surface concentration with highest at stn 5 (0.8 μ mol l^{-1}) and lowest at stn 7 (0.5 μ mol l^{-1}). During monsoon, the lowest NO_2 of 0.3μ mol l^{-1} was in the bottom water and highest value was in pre-monsoon season (0.83 μ mol l^{-1}). NO_2 in surface and bottom water showed significant seasonal variation ($p<0.001$). Pre-monsoon recorded the highest values of NO_3 in the surface water (mean 1.6μ mol l^{-1}) and lowest value (0.15 μ mol l^{-1}) was observed during monsoon. Seasonal variation of surface water NO_3 showed significant variation ($p<0.05$). Surface water NO_3 was highest at stn 2 (2.6μ mol l^{-1}) and lowest value of 0.58μ mol l^{-1} was at stn 1. The maximum values of 1.2 μ mol l^{-1} was recorded at stn 2 and 4, whereas the minimum value of NO_3 in the bottom water was 0.8 μ mol l^{-1} and was recorded at stn 1 and 5. Seasonally, NO_3 was lowest in monsoon (0.028 μ mol l^{-1}) and highest in post monsoon (1.36 μ mol l^{-1}). Figures 2.2 d-f represents the spatio-temporal variation of nutrients in the study area.

The DO in the overlying waters varied significantly. The values were low during monsoon (4.6 mg l^{-1}) and pre monsoon (4. 5 mg l^{-1}). DO was high during post monsoon in the area (5.9 mg l^{-1}). ANOVA detected significant seasonal variation ($p<0.05$) and post hoc Tukey's test detected high DO during post monsoon. Lowest values of surface DO were observed at Stn 6 (4.5 mg l^{-1}) and highest at stn 3 (5.3 mg l^{-1}). Bottom water DO ranged from 4.0 (stn1 and 6) - 5.4 mg l^{-1} (stn 3). The spatio-temporal changes observed in the area were tested to be statistically significant ($p<0.01$). A post hoc Tukey's test detected significantly low DO for monsoon. Figure 2.3 a depicts the variation of DO at seven stations during the three season. Surface water BOD was highest at stn 7 (1.52 mg l^{-1}) and lowest at stn 1 (0.92 mg l^{-1}). Surface water BOD ranged from 0.8-1.3 mg l^{-1}. The post hoc test revealed that mean value at stn 7 during pre monsoon was significantly high. Bottom water BOD values were low during post monsoon (0.5 mg l^{-1}) and high during pre monsoon (1.01 mg l^{-1}). Bottom water BOD did not show significant differences between the stations with values ranging from 0.6-0.8 mg l^{-1} (Table 2.3 and Fig 2.3 b-b').

Dissolved PHC in the surface water, ranged from 6.4-10.5 μ g l^{-1} during pre monsoon and monsoon, respectively and the variations were statistically insignificant. Stn 6 recorded lowest PHC concentration (7.0 μ g l^{-1}) and the highest value was at stn 1 (12.6 μ g l^{-1}). In the bottom waters, the average PHC values ranged from 6.9 -19μ g l^{-1} recorded at stn 7 and stn 2, respectively. PHC in the bottom water was highest during pre monsoon (10.47μ g l^{-1}) and lowest during post monsoon (7.7 μ g l^{-1}). Variation of surface and bottom PHC in the seven stations during the three seasons is shown in Fig 2.3 c and c'. The values for Cd in surface water ranged from 0.11-0.19 μg l^{-1} observed during pre- and post monsoon, respectively. In bottom water, the highest Cd was observed during monsoon (0.14 μg l^{-1}) and lowest during the pre monsoon (0.10 μg l^{-1}; Fig. 2.3 d). Stn 4 detected lowest Cd in the surface (0.06 μg l^{-1}) and bottom waters (0.03 μg l^{-1}) whereas, the highest value was at stn 6 (0.19 and 0.08μg l^{-1}) in surface and bottom respectively). Pb was highest during post monsoon in surface water (1.87 μg l^{-1}) whereas, in bottom waters high value was recorded in pre monsoon (11.2 μg l^{-1}). The lowest Pb in surface and bottom water was observed during monsoon and post monsoon, respectively (Fig. 2.3 e). Stn 7 recorded highest Pb for surface (1.56 μg l^{-1})

and bottom waters (19.9 μg l^{-1}). Stn 6 recorded lowest values of Pb in surface water (1.1 μg l^{-1}) and stn 4 in bottom waters (4.8 μg l^{-1}). Hg in surface water ranged from 35.5- 116 ηg l^{-1} observed during monsoon and pre monsoon, respectively (Fig. 2.3f). In bottom waters, highest values were seen during post monsoon (179.69ηg l^{-1}) and lowest in pre monsoon (136.76ηg l^{-1}). Lowest concentration of Hg in surface and bottom waters was observed at stn 6 (72.2ηg l^{-1}) and stn 2 (108.4) respectively. The highest concentration of Hg was in surface water (82.58ηg l^{-1}, stn 1) and a value of 210.5 ηg l^{-1} (stn 7) was in the bottom water. Results of the two-way ANOVA showed insignificant variance of metal and PHC concentration, except for seasonal concentration of surface water Pb ($p<0.001$; Table 2.4). The seasonal variations of metals at different stations are given in figure 2.3 d-f.

The chl *a* content in the surface water showed decreasing trend from monsoon (10.5μ g l^{-1}) to 0.79 μ g l^{-1} to pre monsoon (Fig.2.4 a). Average value was highest at stn 5 (8.4 μ g l^{-1}) and lowest at stn 1 (2.3 μ g l^{-1}). Seasonally, the chl *a* differed significantly ($p<0.001$). The post hoc test detected significantly high chl *a* for monsoon. Values for bottom water chl *a* was highest at stn 7 (3.6 μ g l^{-1}) and lowest at stn1 (0.9 μ g l^{-1}). The highest chl *a* was observed during monsoon (7.1μ g l^{-1}) and lowest during pre monsoon (0.6μ g l^{-1}). ANOVA for bottom water chl *a*, revealed a significant seasonal variation ($p<0.001$) and the interaction between the season- station ($p<0.001$). Post hoc test showed a significantly high chl *a* at stn 7. Phaeo content had similar temporal pattern to that of chl *a*. Phaeo in surface and bottom water was highest during monsoon (1.9 and 2.8μ g l^{-1}; Fig.2.4 b) and lowest during the pre monsoon (0.2 and 0.36 μ g l^{-1}). Stn 1, recorded lowest surface and bottom water phaeo (0.5 and 0.57 μ g l^{-1}). Surface (2.5μ g l^{-1}) and bottom water (2.27 μ g l^{-1}) phaeo was highest at stn 3. Chl *a* and phaeo values in surface and bottom waters was highest at all the stations during monsoon (Fig 2.4 a-b).

2.3.2 Sediment parameters

Summary of sediment parameter is given in table 2.5. Sediment chl *a* was highest at stn 5 (0.48 μg g^{-1}) and lowest value of 0.17 μg g^{-1} was observed at stn 4 (Table 2.5). Generally, the values were high in post monsoon (0.51 μg g^{-1}; Fig. 2.4 c) and low during pre monsoon (0.059 μg g^{-1}). Similar to other parameters, chl *a*, also illustrated a significant seasonal variation ($p<0.001$; Table 2.6). Average sediment OC was high at stn 5 (1.8%) and lower value of 1% was recorded at stn 2. Seasonally, OC was highest during post monsoon at all the stations (Fig 2.4d) with average value of (1.86%) and lowest during monsoon (1.1 %). ANOVA demonstrated significant differences among the stations ($p<0.05$), seasons ($p<0.001$) and a significant season x station interaction ($p<0.05$). Tukey's post hoc test for multiple comparisons showed that OC was significantly low at stn 2 during monsoon and highest was at stn 5 in post monsoon.

Heavy metals in the sediment were also estimated and the results are presented in figure 2.4 e-g. Seasonally, the highest Cd was recorded during monsoon (0.08$\mu g\ g^{-1}$) and lowest during the post monsoon (0.054 $\mu g\ g^{-1}$). Stn 3 had lowest concentration of Cd (0.03$\mu g\ g^{-1}$) and highest value was at stn 6 (0.08$\mu g\ g^{-1}$). Sediment Pb was highest during pre-monsoon (13.10 $\mu g\ g^{-1}$) and lowest values were observed during the monsoon (7.4 $\mu g\ g^{-1}$). Stn 7 recorded the highest Pb (21 $\mu g\ g^{-1}$) and low value was at stn 3 (4.8 $\mu g\ g^{-1}$). Mercury was highest at stn 7 (190 $\eta g\ g^{-1}$) and lowest of 118 $\eta g\ g^{-1}$ was observed at stn 1. Post monsoon recorded highest concentration of Hg (167.89 $\eta g\ g^{-1}$) and lowest in monsoon (99.75 $\eta g\ g^{-1}$). Sediment metal concentration showed non-significant spatio-temporal variations.

The sediment texture in the study area was heterogeneous. Station 1, 5, 6 and 7 and was dominated by silt and stns 2-4 had a mixture of sand and silt. The sand content at stn 2-4 varied from 45-60% (Fig. 2.4h). Sediment texture in the stns 2-4 showed higher variation throughout the year.

2.3.3 Correlation of Physico-Chemical parameters

The linear correlation coefficients between the physico-chemical variables of monthly data and are given in table 2.7. In general, surface water temperature had significant strong correlation with salinity ($r= 0.76$; $p<0.01$), BOD ($r= 0.67$; $p<0.05$), Hg ($r=0.56$; $p<0.05$). BOD was strongly correlated with water Hg (0.68; $p<0.01$). Sand content was negatively correlated with sediment metals, however not statistically significant. A negative correlation was observed between OC and sand and positive relationship with silt and clay however the correlation was not statistically significant. Water chl *a* showed significant positive correlation with water phaeopigment ($r=0.98$; $p<0.001$), and sediment chl *a* ($r=0.72$; $p<0.01$).

2.3.4 Principal Component Analysis

The Principal Component Analysis (PCA) was carried in order to find the parameters, which influenced the environment of the study area. In PCA, the eigen values are normally used to determine the number of principal components (PCs) that can be retained for further study. A scree plot for the eigen values obtained showed a pronounced change of slope after fourth eigen values. Therefore, the first four PC were retained, as they explained 68.9% of the variance in the data (Table 2.8; Fig.2.5). The first principal component (PC1) explained 35.5% of variance and was influenced by salinity, NO_2, water Pb and Hg were negatively loaded. Surface and bottom water chl *a* and bottom water PO_4 showed a positive loading on this axis. Monsoon showed highest score on the first PC1 and therefore, it can be concluded that the first component is strongly influenced by temporal variability. PC2 explained 18.9% of the variability and was negatively contributed by surface water DO, sediment chl *a* and sand. Bottom water BOD and silt was positively loaded on this axis. PC 3 and PC4 explained 7.8% and 6.7% of the variability respectively and related to the increased harbour activities. This is indicated by positive loading of Pb, Hg (sediment and water) and BOD on PC3. Stn 5, 6, 7 during pre monsoon had the highest scoring on this axis. PC4 were positively loaded by water Cd, chl *a* (sediment) organic carbon and silt. Stn 5 during post monsoon had highest score on PC4.

2.4 Discussion

Physico-chemical parameters showed a significant temporal variation influenced by the monsoonal freshwater runoff. In general, temperature, salinity and pH (surface and bottom water) showed a similar seasonal pattern for all the stations. Seawater temperature showed an increase from monsoon to post monsoon with a drop during winter (December) and again increased during pre monsoon (summer), a characteristic feature of the coastal estuaries. Surface and bottom water temperature showed a similar horizontal distribution with a mean difference of 0.5°C. Highest temperature was observed during May, when the solar radiations were highest (28.70 mw s^{-1}). Surface and bottom water salinity was similar during post- and pre monsoon except during monsoon, indicating that the area is well mixed. During monsoon the bottom salinity was higher than surface. The monsoon runoff is an important factor to influence the salinity of an area. The runoff in Zuari estuary is much greater than the volume of the river channel. The volume of Zuari is ≈ 270 Mcum including the Mormugao Bay (Shetye et al, 2007). The heavy runoff occurring during the summer monsoon every year (June-July) completely flushes the Zuari estuary, turning the estuarine water fresh (Shetye et al, 2007).

Bottom and surface water DO increased rapidly after monsoon season and showed a decline during late pre monsoon (May). The low DO in monsoon may be due to the upwelling during the southwest monsoon. Thus, when upwelled waters occupy the bottom, the oxygen concentration decreases (Shenoy and Patil, 2003). The region receives considerable amount of untreated sewage from the city (25 t, MC of Goa, 2003), but we measured no oxygen below the standard levels (3 mg l^{-1}) prescribed by CPCB (Table 2.9). Therefore, even though the estuary receives high organic and suspended loads from the natural and anthropogenic sources, the DO values never approached extremely low levels throughout the study period. This probably was due to the strong hydrodynamic nature of the area resulting in water circulation and extensive mixing. The available energy is much larger during the summer season than during the rest of the year and expected to have a major impact on vertical mixing near the mouths of the estuaries in the Mormugao Bay (Shetye et al. 2007). The role of estuarine circulation in affecting bottom DO distributions was also observed in other estuaries worldwide (Ishikawa et al. 2004; Yin et al. 2004). It appears that vertical distributions of DO in estuaries are affected by different physical factors in different systems. Stanley and Nixon (1992) examined the relationships among bottom DO, vertical stratification, and factors responsible for stratification-destratification in the Pamlico River Estuary and found that hypoxia develops only when vertical stratification and warm water temperature occur concurrently. The reduced DO in May was due to the increased water temperature in pre monsoon, which is known to negatively affect the solubility of DO (Vega et al. 1998). It was interesting to note that at all the stations, BOD values attain a peak during the pre monsoon. This may be due to the summer evaporation and reduced freshwater flow resulting in increased BOD.

Nutrient levels showed significant seasonal variation. NO_3 and NO_2 were lowest during monsoon. PO_4 remains highest during monsoon and maximum values were recorded in the harbour station. Chl *a* was high during monsoon season, a phenomenon common in the tropical estuaries (Shenoy and Patil 2003; Madhu et al. 2007). However, the values were not correlated with nutrient or any other parameters except water and sediment phaeopigment (Table 2.7). The results did not follow the conventional correlation of chl *a,* which may be due to the complex relationship of chl *a* concentration with multiple variables. The values of nutrients and chl *a* in the Mormugao bay were low compared to the Cochin backwaters (Madhu et al. 2007).

Granulometry showed a significant variation among the stations with outer harbour (stn 2- 4) dominated by sand. Silt prevailed at stn 1 and in the inner harbour (stn 6-7). The granulometry of the Mormugao agreed well with the typical distribution of sediment in the estuary i.e .highest sand content towards the mouth region and dominance of fine sediment towards the inner part of the estuary. Seasonally, sediment texture showed a slight variation in inner harbour. Outer harbour stations however, showed an increase in sand content during the monsoon. The sediment texture in the area is related to the hydrodynamic conditions and the influence of river inputs.

Sediment OC varied significantly across the sampling stations and months. Highest OC was observed in the harbour stations which also had high highest silt content. Generally, the OC content is directly related to the sediment texture with higher values being associated with fine particles (Sharp 1973). The harbour receives large amount of domestic sewage from the Vasco city, Mormugao municipal area and fishing activities (Ansari et al. 1994). Furthermore, petroleum hydrocarbon from spills and harbour activities adds to the OC of an area (Kiyashko et al. 2001) indicating that organic pollution to be a major environmental concern in the Mormugao harbour.

The PCA analysis of the physico-chemical parameters in water and sediment showed a strong seasonal influence. Salinity, temperature, chl *a*, nutrients and sediment texture have strong loading in PC1 axis indicating their importance in the study area. Salinity and temperature were lowest during monsoon season caused by heavy rainfall and runoff.

The harbour and channel stations had highest scoring on the third and fourth axis during post- and pre monsoon. The metals (Pb and Hg) concentrations gave significant loading on these axes. The high metal concentration in harbour and channel appear to have direct link with anthropogenic activities. Increased shipping activities which peaks after the monsoon, therefore can be the main sources of metal in the area. Paint residues are the main sources of Pb in the harbour region. A comparative study of three estuaries in NW Spain showed highest values of Pb in the estuaries, which had port (Lorenzo et al. 2006). Further, the authors suggest that the paint residues from harbours not only contribute to higher Pb values but also source of Cd and Co. Other sources of pollutants in the area include waste discharge from the surrounding areas, which discharges directly into the harbour area.

In general, the concentration of contaminants in water and sediment were within the limits subscribed for harbour region. This could be due the hydrodynamic nature of the study area. The flushing by tides results in the quick dispersion of the contaminants into the sea. The maximum current speed in this estuary occurs during the monsoon whereas an average of ~ 20 cm s^{-1} occurs after monsoon (Jayakumar et al. 1996). Further, the flushing in the area is increases by ten folds due to heavy runoff of the Zuari estuary during the SW monsoon (Shetye et al. 1995; Shetye et al. 2007). During the monsoon, the freshwater influx in the area is at the rate of >10,000 ML day^{-1} (Shetye et al. 1991). The shipping activities are very less during monsoon compared to the other seasons. Further, because of the rough weather at the mouth of estuary, loading of iron is at its minimum during monsoon. Generally, the shipping and mining activities contribute to trace metals and other pollutants in the area. However, the dilution due to precipitation and reduced shipping activities could help in lowering the metal concentrations during the monsoon. Further, the values for PHC and sediment metal were within the acceptable limits recommended for harbour areas (CPCB 1993). Moreover, organic matter, salinity, temperature are important factors controlling the abundance of trace metals (McLusky 1986; Rubio et al. 2000). Hg have low bioavailability when organically bound (Langston 1982) and bioavailability of Pb is reduced in sediment with high organic matter (Bryan and Langston, 1992). Hg and Pb were low in stations with higher organic carbon content. Further, Fe and manganese oxides (oxyhydroxides) are strong scavengers of metals, affecting trace metal mobilization, as they precipitate under oxic condition and dissolve in anoxic environment. It is well documented that metals are bound to different components and the measurement of total concentration of metals do not reflect the potential bioavailability (Loring 1981). Since, Fe and Mn are the main ore exported from the harbour, the values of these metals were also higher in the study area. Iron concentration in the Zuari water ranged from 0-20 mg l^{-1} during the study period and in sediment, the values were 1- 16 mg l^{-1} (Mesquita and Kaisary 2007).

2.5 Conclusion

The Zuari is a dynamic estuarine ecosystem and is highly influenced by the monsoonal rainfall. As a result, the Zuari estuary is a complex blend of continuously changing habitats. Consequently, flushing of contaminants out of the system is also high and this could be the main reason of low contaminants in the area.

Table 2.1 a
Geographical location and water depth at sampling stations

Station No.	Latitude (°) N	Longitude (°) E	Water Depth (m)
1.	15°25' 35"	73°47' 30"	14.0
2.	15°25' 48"	73°47' 55"	8.0
3.	15°25' 30"	73°48' 10"	8.0
4.	15°26' 01"	73°48' 50"	7.0
5.	15°25' 04"	73°47' 30"	12.5
6.	15°25' 00"	73°48' 24"	7.0
7.	15°25' 02"	73°48' 51"	6.0

Table 2.1 b
List of environmental parameters studied and abbreviations used

Parameters	Surface water	Bottom water	Sediment
Temperature	ST	BT	-
Salinity	SS	BS	-
pH	S pH	B pH	-
Dissolved Oxygen	S DO	B DO	-
Biological Oxygen Demand	S BOD	BBOD	-
Nitrate	S NO_3	B NO_3	-
Nitrite	S NO_2	B NO_2	-
Phosphate	S PO_4	B PO_4	-
Petroleum Hydrocarbon	SPHC	B PHC	-
Cadmium	S Cd	B Cd	Sed Cd
Lead	S Pb	B Pb	Sed Pb
Mercury	S Hg	B Hg	Sed Hg
Chlorophyll a	S Chl *a*	B Chl *a*	Sed Chl *a*
Phaeopigment	S Phaeo	B Phaeo	Sed Phaeo
Organic Carbon	-	-	OC

Table 2.2
Mean (SD) values of the surface water variables at the seven locations of Mormugao harbour during September 2003-July 2004*

	Stn1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7
Temperature (°C)	29.3±1.3	30.2±1.3	29.8±1.3	29.8±1.3	29.9±1.4	29.9±1.5	29.9±1.5
Salinity (psu)	30.3±4.3	29.0±4.3	31.8±4.3	31.8±4.8	32.1±4.5	31.3±4.5	31.4±4.4
pH	7.9±0.1	8±0.05	8±0.02	8.0±0.03	8.1±0.05	8.0±0.02	8.1±0.04
PO_4 µ mole l^{-1}	1.3±0.28	0.86±0.5	0.88±0.18	1.0±0.22	0.96±0.27	1.0±0.33	1.7±0.96
NO_2 µ mole l^{-1}	0.3±0.23	0.4±0.26	0.47±0.46	0.5±0.3	0.4±0.35	0.4±0.32	0.4±0.28
NO_3 µ mole l^{-1}	0.58±0.29	2.6±3.2	1.7±0.96	0.85±0.011	0.8±0.22	0.65±0.58	1.26±0.008
DO mg l^{-1}	5.1±0.8	5.4±1.1	5.3±0.8	5.0±0.9	5.2±0.6	4.5±1.3	4.7±1.4
BOD mg l^{-1}	0.9±0.3	1.1±0.36	1.2±0.2	1.3±0.2	0.9±0.23	1.05±0.46	1.5±0.8
PHC µg l^{-1}	12.5±5.9	9.6±3.6	9.7±2.6	8.1±0.6	8.1±0.4	7.0±1.5	7.3±1.2
Cd µg l^{-1}	0.17±0.12	0.09±0.019	0.09±0.03	0.06±0.011	0.18±0.12	0.19±0.16	0.17±0.07
Pb µg l^{-1}	1.42±0.97	1.2±0.67	1.25±0.86	1.2±0.97	1.3±0.4	1.09±0.81	1.56±0.35
Hg ηg l^{-1}	82.5±49.4	61.5±35.9	69.9±32.8	82.1±50.7	77.2±41.5	72.2±30.03	82.2±54.5
Chl *a* µg l^{-1}	2.3±2.4	3.8±2.6	4.8±5.7	4.8±3.4	8.4±9.3	8.1±9.0	3.2±3.1
Phaeo µg l^{-1}	0.57±0.49	0.7±0.59	2.4±3.7	1.04±0.88	0.83±0.78	0.85±0.5	0.88±0.57

*Source: Anon 2004

Table 2.3
Mean (SD) values of the bottom water variables in the seven locations of Mormugao harbour during September 2003-July 2004*

	Stn1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7
Temperature (°C)	28.6±1.0	29.8±1.1	29.2±1.1	29.17±1.1	29.62±1.04	29.67±1.1	29.7±1.15
Salinity (psu)	33.9±0.8	33.6±1.5	33.4±2.4	32.5±3.5	33.7±1.6	32.9±1.2	32.6±2.0
pH	7.9±0.3	8±.07	8±0.05	7.9±0.07	8±0.12	8±0.1	8±0.1
PO_4 µM	1.7±0.5	1.1±0.46	1.5±0.76	1.5±0.76	1.6±0.9	1.3±0.5	1.2±0.42
NO_2 µM	0.6±0.3	0.6±0.5	0.5±0.6	0.6±0.4	0.8±0.5	0.6±0.5	0.5±0.4
NO_3 µM	0.8±0.7	1.2±1.3	1.1±1.3	1.2±1.5	0.8±0.7	1±1.1	0.9±1
DO mg l^{-1}	4.1±2.1	5.0±0.76	5.3±0.46	4.6±1.2	4.1±12.0	5.1±1.0	5.2±0.3
BOD mg l^{-1}	0.8±0.3	0.6±0.3	0.7±0.4	0.8±0.3	0.7±0.5	0.7±0.5	0.6±0.5
PHC µg l^{-1}	8±3.8	19±28	8±5	7±4	7±5	7±4	6.7±4.6
Cd µg l^{-1}	0.06±0.027	0.06±0.05	0.07±0.026	0.03±0.001	0.06±0.03	0.08±0.03	0.05±0.02
Pb µg l^{-1}	10.77±2.67	5.0±0.42	7.8±3.5	4.8±1.69	7.36±2.9	7.6±0.32	19.9±15.0
Hg ηg l^{-1}	189.2±58.7	108.3±54.4	143.5±17.67	187.8±29.9	161.6±62.9	141.1±43.3	210.5±52.18
Chl *a* µg l^{-1}	0.9±1	1.1±1	1.8±2	2.7±3.2	1.5±1.4	2±2.3	3.6±6.5
Phaeo µg l^{-1}	0.57±0.5	1.1±1.1	2.2±2.2	0.9±0.62	1.2±1.04	2.3±2.9	1.34±1.28

*Source: Anon 2004

Table 2.4
Two-way ANOVA of water parameters between stations (7), season (3) and their interaction. F statistic and probability (p)

		Surface		Bottom	
Parameters		**F**	**P**	**F**	**P**
Temperature	Season	12.66	<0.001	9.03	<0.001
(^{0}C)	Station	0.43	0.84	1.42	0.25
	S x S	0.16	0.99	0.24	0.99
Salinity (PSU)		84.15	<0.001	110.7	<0.001
		1.15	0.36	12.1	<0.001
		1.32	0.26	8.5	<0.001
PO4 μM l^{-1}		7.4	<0.001	10.96	<0.001
		1.25	0.32	1.76	0.15
		0.5	0.92	0.57	0.9
NO3 μM l^{-1}		6.32	0.0016		NS
		1.16	0.36		NS
		1.07	0.43		NS
NO2 μM l^{-1}		79	<0.001	44.13	<0.001
		2.5	0.055	1.79	0.148
		5.0	<0.001	3.6	0.002
DO mg l^{-1}		4.2	0.011	33.0	<0.001
		0.56	0.75	4.18	0.006
		0.29	0.99	1.7	0.09
BOD mg l^{-1}		7.6	<0.001	6.7	0.001
		3.5	0.013	0.21	0.96
		2.3	0.028	0.67	0.82
Chl a μg l^{-1}		5.8	0.002	20.9	<0.001
		0.76	0.60	4.49	0.004
		0.38	0.98	2.6	0.014
Phaeo (μg l^{-1})		3.8	0.017	10.62	<0.001
		0.54	0.7	2.00	0.11
		0.9	0.59	0.93	0.56

Table 2.5
Mean(SD) values of the sediment variables in the seven locations of Mormugao harbour during September 2003-July 2004*

	Stn1	**Stn 2**	**Stn 3**	**Stn 4**	**Stn 5**	**Stn 6**	**Stn 7**
*Cd $\mu g\ g^{-1}$	0.06±0.0 4	0.07±0.08	0.03±0.01	0.04±0.03	0.06±0.04	0.08±0.07	0.05±0.03
*Pb $\mu g\ g^{-1}$	10±2.5	5.4±2	4.8±2	6±3	14.6±8.5	7.7±1.7	21±17
*Hg $\eta g\ g^{-1}$	118±54	134±58	179±58	155±88	180.0±79	146±71	190±150
*Sand %	10±17	45±37.7	12.9±20	21±32.7	2±1.2	7.1±3.5	7±2.9
*Silt %	81.5±14.5	50±34.9	80.3±17.9	71±29.4	89±1	84±3	8.6±1
*Clay %	8.6±2.7	4.5±2.8	6.7±2.3	7.4±3.3	8.9±1	8.6±1	8±1
Chl *a* $\mu g\ g^{-1}$	0.25±0.26	0.13±0.14	0.28±0.39	0.17±0.25	0.48±0.59	0.45±0.40	0.27±0.32
OC %	1.5±0.83	1.01±0.70	1.30±0.8	1.57±0.88	1.8±1.2	1.4±1.2	1.3±0.7

*Source: Anon 2004 for metal and granulometry

Table 2.6
Two-way ANOVA of sediment parameter between stations (7), seasons (3) and their interaction in the Mormugao harbour. F statistic and probability (p)

Parameters		**F**	**P**
Chl a	Season	4.98	<0.0027
	Station	0.93	0.48
	S x S	0.30	0.99
OC		51	<0.001
		3.36	0.01
		1.99	0.03

Table 2.7

Correlation matrix between environmental parameters. * $p<0.05$; ** $p<0.01$; *** $p<0.001$

	Sal	Temp	pH	DO	BOD	PO_4	NO_2	NO_3	W Chl a	Wphae	PHC	WHg	WCd	WPb	OC	Schl a	Sed Cd	Sed Pb	Sed Hg	Sand	Silt	C
Sal	1.00																					
Temp	****0.76**	1.00																				
pH	0.34	0.22	1.00																			
DO	0.40	0.20	-0.30	1.00																		
BOD	0.28	***0.67**	0.28	-0.11	1.00																	
PO_4	****-0.72**	*****-0.81**	-0.53	-0.06	-0.51	1.00																
NO_2	0.00	-0.04	0.11	0.02	0.19	0.01	1.00															
NO_3	0.27	-0.14	***0.66**	-0.04	0.01	-0.09	***0.55**	1.00														
W Chl a	-0.38	-0.11	-0.16	0.21	0.03	-0.04	-0.38	-0.47	1.00													
W Phaeo	-0.35	-0.12	-0.12	0.17	-0.03	-0.12	-0.33	-0.44	*****0.98**	1.00												
W PHC	0.19	0.36	-0.12	0.02	-0.02	-0.16	-0.18	-0.43	-0.03	-0.08	1.00											
W Hg	0.50	***0.56**	0.26	-0.18	***0.68**	***-0.60**	0.03	0.18	-0.16	-0.12	-0.32	1.00										
W Cd	0.23	-0.13	***0.60**	-0.25	0.00	0.00	-0.03	***0.55**	-0.36	-0.38	0.13	0.04	1.00									
W Pb	***0.57**	0.26	-0.01	****0.78**	-0.29	-0.35	0.02	0.11	0.01	0.05	0.25	-0.20	-0.04	1.00								
OC	0.26	-0.22	0.45	0.38	-0.18	0.07	0.33	****0.70**	-0.30	-0.29	-0.21	-0.25	0.58	0.44	1.00							
Sed chl a	-0.04	-0.17	0.11	0.25	-0.17	-0.04	-0.40	-0.07	****0.72**	0.69	0.11	-0.14	0.25	0.19	0.08	1.00						
Sed Cd	-0.22	-0.06	0.38	-0.40	0.50	-0.07	***0.62**	0.43	0.07	0.08	-0.28	0.32	0.17	-0.52	0.01	0.07	1.00					
Sed Pb	0.35	0.46	-0.35	0.20	0.26	-0.23	-0.34	-0.30	-0.17	-0.20	-0.06	0.49	-0.36	0.15	-0.38	-0.37	-0.51	1.00				
Sed Hg	0.30	0.52	0.02	0.35	0.49	-0.54	-0.10	-0.29	0.56	0.54	0.39	0.27	-0.03	0.32	-0.15	0.55	0.14	0.07	1.00			
Sand	0.18	0.21	-0.07	0.35	-0.12	-0.48	-0.28	-0.21	0.54	0.63	-0.18	0.18	-0.55	0.47	-0.28	0.31	-0.28	0.33	0.35	1.00		
Silt	-0.18	-0.22	0.05	-0.34	0.10	0.50	0.27	0.20	-0.55	-0.64	0.19	-0.19	0.55	-0.46	0.28	-0.30	0.26	-0.33	-0.36	-1.00	1.00	
Clay	-0.18	-0.13	0.23	-0.41	0.28	0.34	0.37	0.25	-0.49	-0.56	0.08	-0.10	0.50	-0.52	0.30	-0.38	0.41	-0.38	-0.32	*****-0.96**	*****0.95**	1

Table 2.8
Principal component analysis (PCA) loading of water and sediment parameters.

Variable	PC1	PC2	PC3	PC4
SS	**-0.267**	-0.052	-0.005	0.074
BS	-0.24	-0.054	-0.118	0.05
ST	-0.24	0.12	0.1	0.029
BT	-0.24	0.12	0.104	0.028
S pH	-0.07	**-0.27**	**0.213**	0.088
B pH	-0.192	-0.101	0.157	-0.029
S NO_2	**-0.252**	0.045	0.04	0.008
B NO_2	-0.216	0.125	0.024	0.116
S NO_3	-0.212	-0.114	-0.013	-0.038
B NO_3	-0.214	**-0.201**	-0.03	-0.067
S PO_4	0.215	0.145	-0.009	-0.013
B PO_4	**0.243**	0.062	-0.001	0.139
S Phaeo	0.09	**-0.212**	0.081	0.049
B Phaeo	0.177	-0.129	0.105	-0.069
S Chl a	**0.202**	-0.173	0.085	0.012
B Chl a	**0.215**	-0.066	0.115	-0.014
S DO	-0.038	**-0.313**	-0.192	0.073
B DO	-0.119	-0.189	-0.193	**-0.207**
S BOD	-0.006	0.215	**0.371**	-0.107
B BOD	-0.126	**0.259**	-0.071	-0.042
S PHC	0.12	-0.071	-0.154	0.016
B PHC	-0.008	0.103	**-0.246**	0.025
S Cd	-0.007	-0.094	0.021	**0.428**
B Cd	0.063	-0.095	0.099	**0.322**
S Pb	**-0.227**	-0.17	-0.079	0.066
B Pb	-0.217	-0.197	-0.038	0.14
S Hg	**-0.238**	0.104	0.032	0.002
B Hg	-0.217	0.116	**0.272**	0.012
Sed Cd	0.023	0.08	-0.085	0.173
Sed Pb	-0.059	0.166	**0.416**	0.16
Sed Hg	0.123	-0.011	**0.367**	0.094
Sed Chl a	0.076	**-0.266**	0.062	**0.276**
OC	-0.046	-0.22	0.057	**0.345**
Sand	-0.026	**-0.247**	0.154	**-0.356**
Silt	0.035	**0.236**	-0.097	**0.375**
Clay	-0.018	0.219	**-0.325**	0.189
Eigen values	12.8	6.79	2.79	2.4
%Variation	35.5	18.9	7.8	6.7
Cum.% Variation	35.5	54.4	62.2	68.8

Table 2.9
Primary water quality criteria for SW1 to SW5 category water (CPCB India)*

Type of water	DO (mg l^{-1})	BOD (mg l^{-1})
SW1: Ecologically sensitive area/ mariculture	5	–
SW2: Bathing and commercial fishing	4	3
SW3: Industrial cooling	3	3
SW4: Harbour development	3	5
SW5: Navigational and controlled waste disposal	3	5

*Source: CPCB (1995)

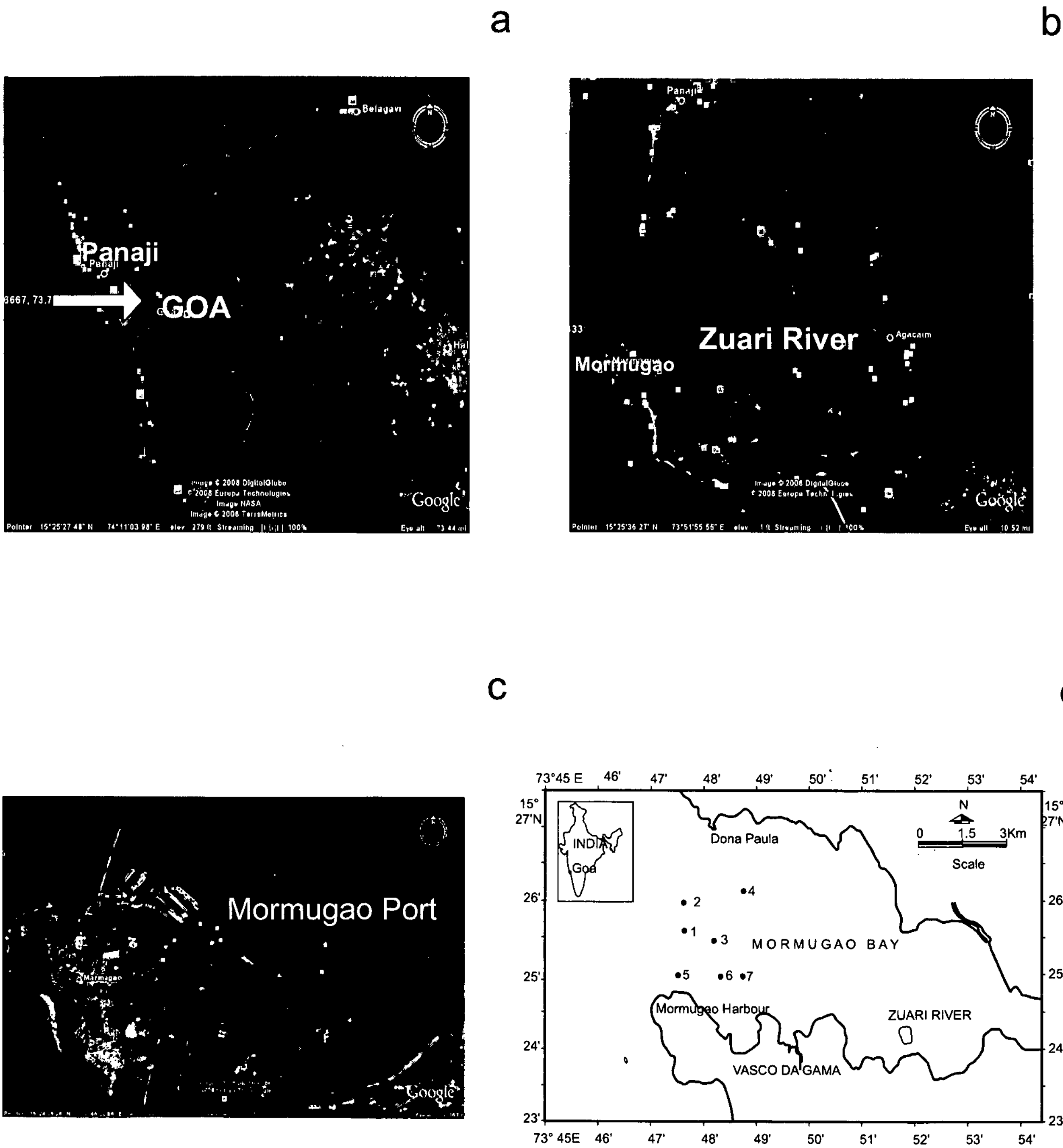


Fig 2.1 Location of the study area: Map of Goa (a), Zuari estuary (b),Mormugao Port (c) and location of sampling site (d)

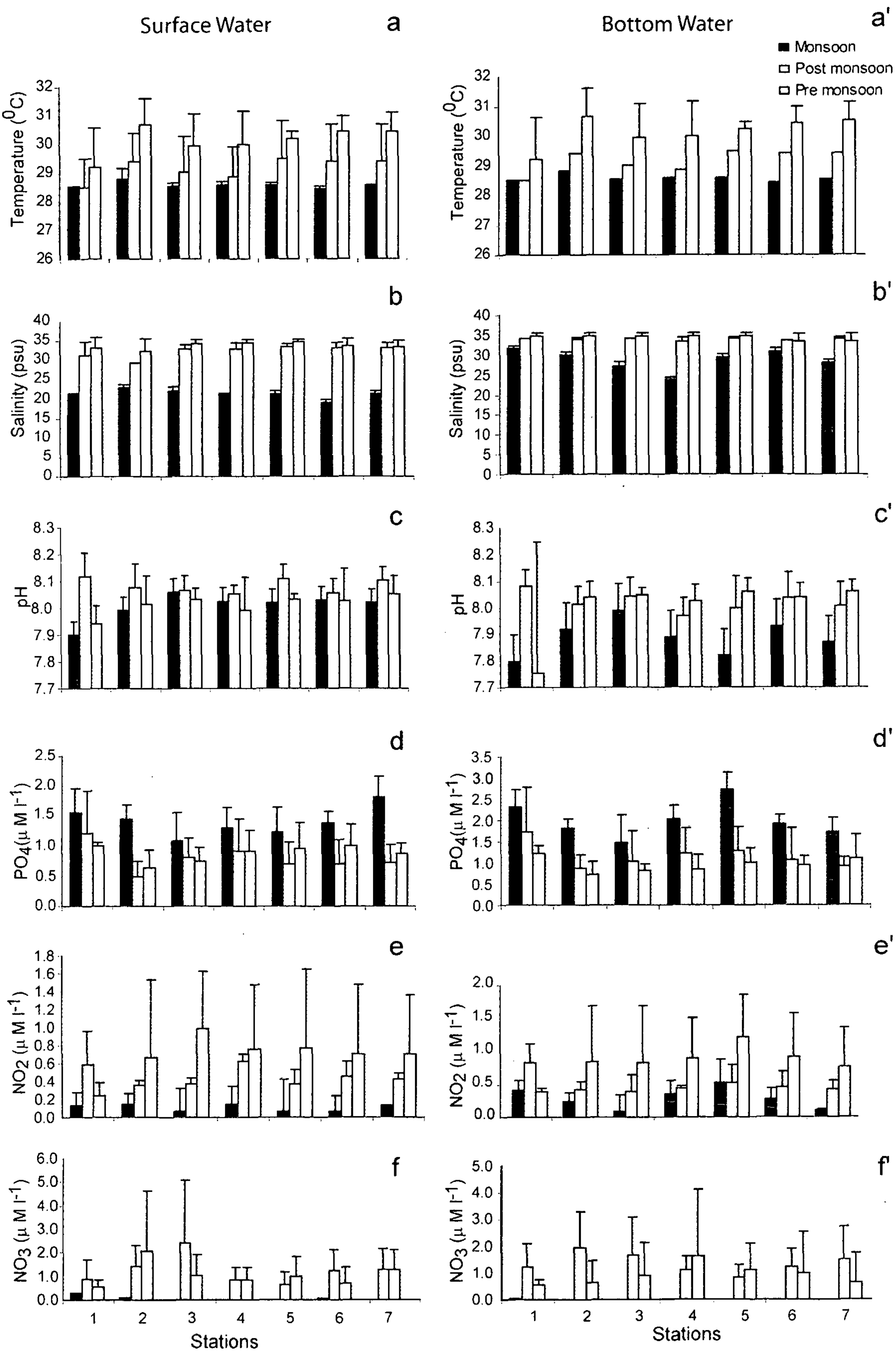


Fig 2.2 Seasonal variation (±SD) in surface and bottom water temperature (a), salinity(b), pH (c) phosphate(d), nitrite (e) and nitrate(f).

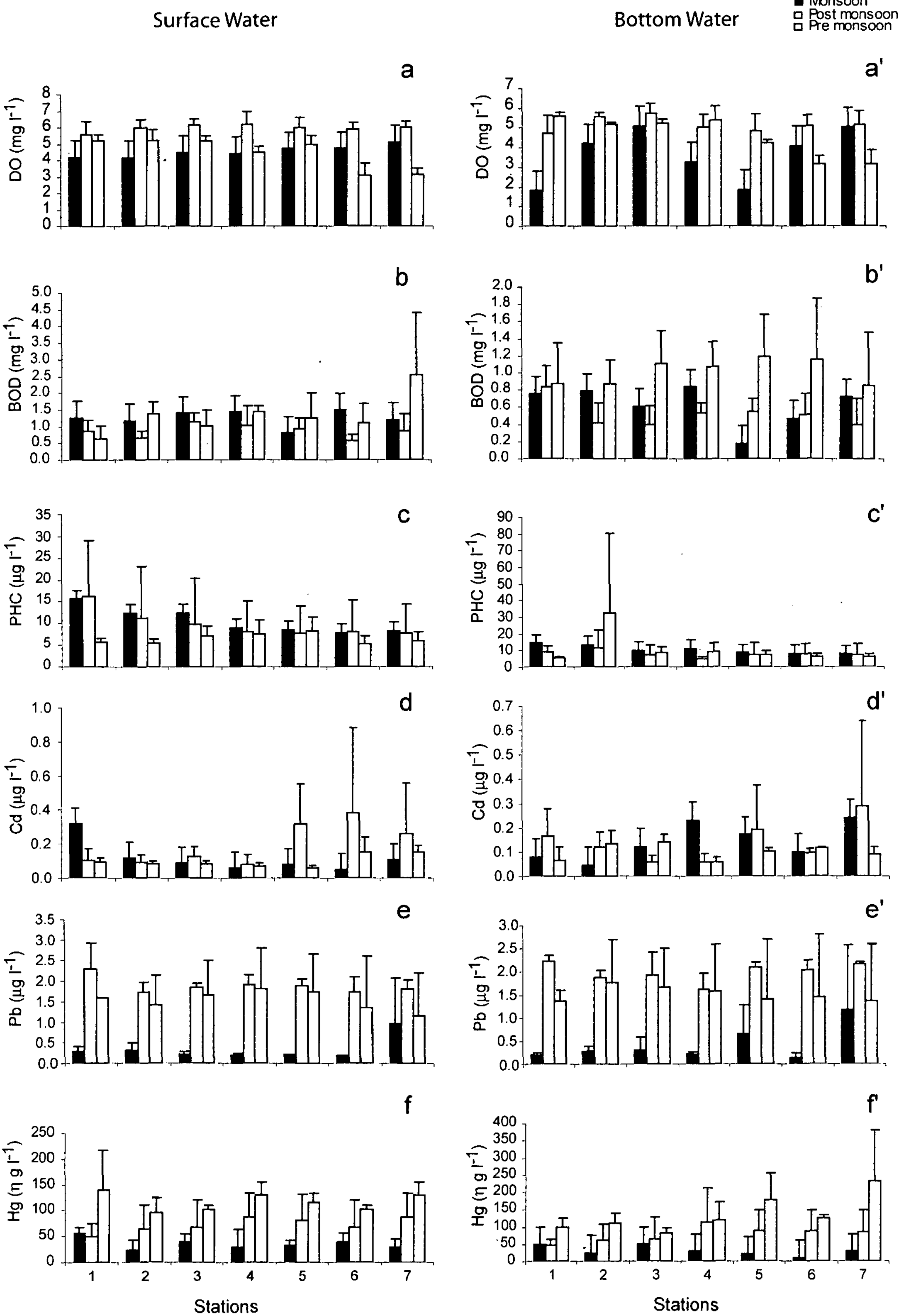


Fig 2.3 Seasonal variation (±SD) in surface and bottom water DO(a), BOD(b), PHC(c), Cd (d) Pb(e) and Hg(f).

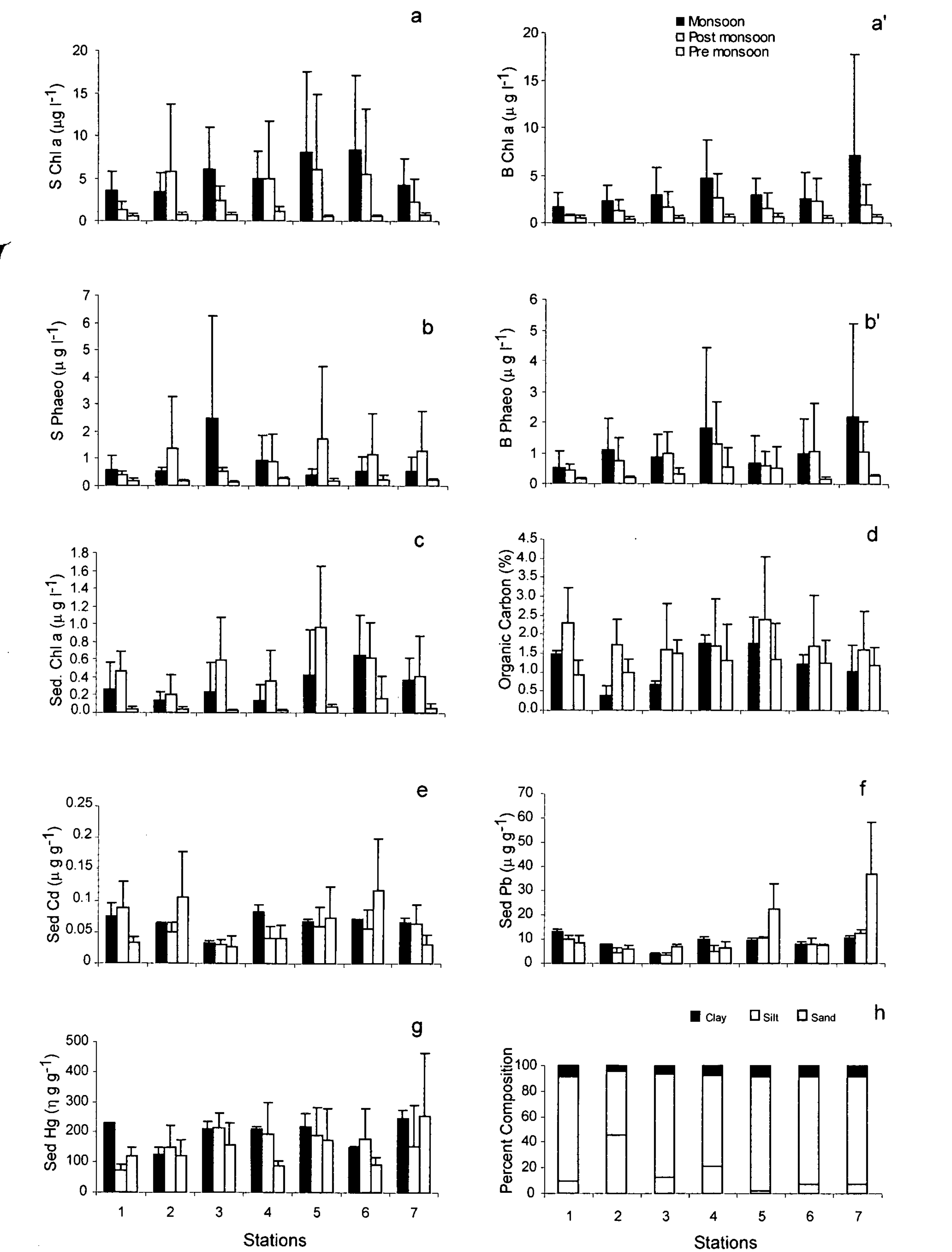


Fig 2.4 Seasonal variation (±SD)of surface and bottom water chl *a* (a), phaeopigment (b), sediment chl *a* (c),organic carbon(d) sediment Cd(e), Pb(f), Hg(g) and sediment texture (h)

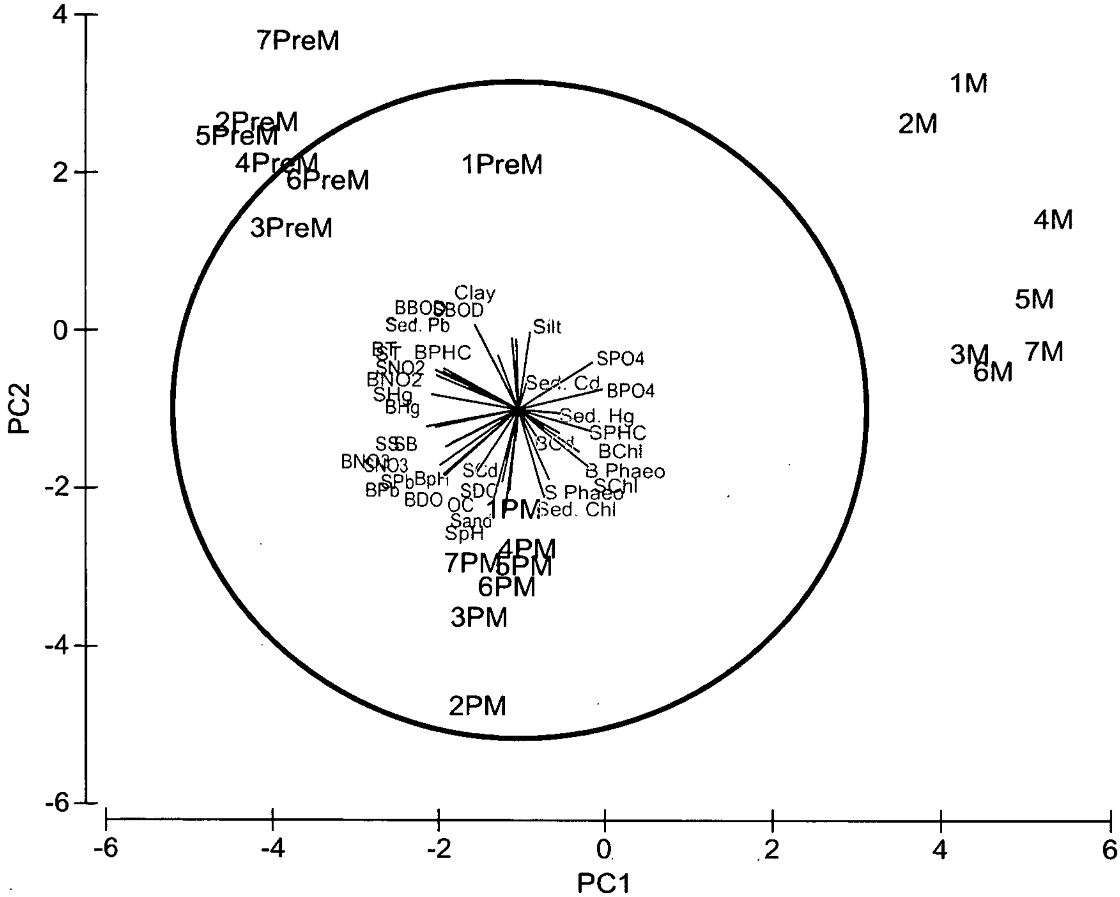


Fig 2.5 PCA of the environmental parameters .(M Monsoon; PreM Premonsoon; PM post monsoon)

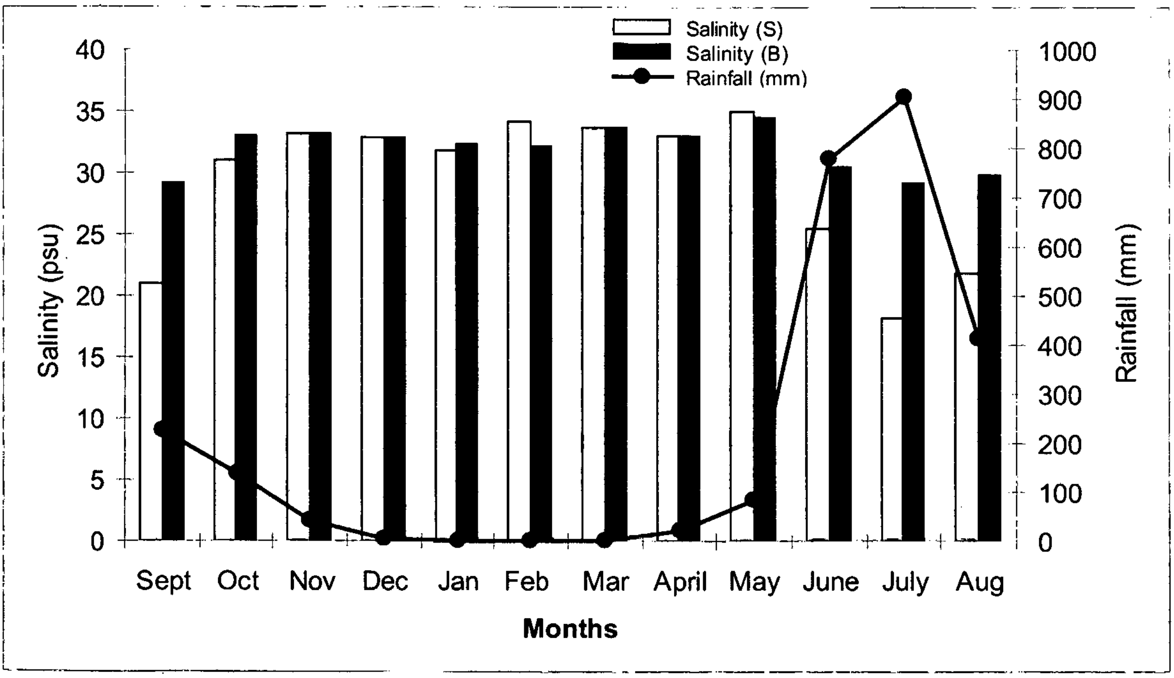


Fig 2.6 Variation in rainfall and salinity in the study area during 2003-04

Chapter 3

Spatial-temporal variation and Impact of harbour activities on the macrobenthic community.

3.1 Introduction

Seaports are very complex systems with a wide range of environmental issues. The various harbour activities modifies and creates new habitats and communities. Furthermore, in port areas and in their vicinity, several other activities such as industries, fisheries are also carried out which further impact the environment. Finally, the continuous movements of ships in confined area increase the frequency of accidents and the risk of release of hazardous material (Trozzi and Vaccaro 2000).

In spite of the importance of maritime activity in the Mormugao harbour and the resulting potential environmental impacts, studies on the marine benthic communities are lacking. Previous work on the benthic communities in the area has been restricted to locations outside the harbour or based on one time sampling. Benthic studies in the area are restricted to the seasonal and temporal variation of macrofauna in the Zuari estuary. Study on the spatio-temporal variation of macrofauna in the Zuari estuary was firstly provided by Parulekar et al (1980) followed by periodical assessment of the entire estuarine system by Ansari et al (1986, 1995a, 2007). Species succession of the estuarine system was studied earlier by Harkantra and Rodrigues (2003). Most of these studies in the estuary were conducted at large scale, which miss smaller patterns of variation caused by natural and anthropogenic influence. An attempt was made by Ansari et al (1994) to study the marcofaunal community of the harbour; however it was based only on single sampling that does not consider the temporal variability. The lack of knowledge about the temporal variability makes it difficult to distinguish between natural and anthropogenic disturbance (Morrisey et al. 1991; Clarke and Warwick 1994).

In this study, the macrobenthic fauna of the harbour was analysed seasonally and compared with earlier published data. Such comparative analysis allows to illustrate how changes have occurred in the ecosystem through the years. Although historical analyses of ecological conditions are not new, they are not used as a routine or widespread technique. Pearce (1999) pointed out the value of historical studies and the need for more case studies. As current ecological conditions in an area is usually a complex mix of impact accumulated over many decades. Further, ports are vulnerable to invasion as they are naturally and anthropogenically disturbed habitats. It is estimated that 10,000 different species are being transported between biogeographic regions in ballast tanks alone (Carlton 1999). A prerequisite for the understanding of invasive species and its control in the waters world wide is the knowledge of the current distribution and abundance of species in the major harbours of the world. Therefore the present study is aimed at understanding-

- ❖ The spatio-temporal variability of the macrofauna in the harbour
- ❖ The long-term changes in the macrobenthic species composition due to harbour activities

3.2 Materials and Methods

3.2.1 Sampling and Analysis

Macrofaunal samples were collected monthly with a van Veen grab (0.04 m^2) from the seven stations (Fig. 2.1d). Sediment were sieved on 0.5 mm mesh sieve and fixed in neutralized 5% formalin-rose Bengal solution. In the laboratory, the samples were again washed, sorted, identified and counted. Biomass was determined by wet weight method. Taxonomic identification was based on literature from various sources.

3.2.2 Data Analysis

Faunal data was initially processed using MS Excel. Margalef's species richness (*d*), Shannon Wiener diversity (*H'*) and Peilou's evenness (*J'*), was calculated. Multi Dimensional Scaling (MDS) and Bray- Curtis similarity index was constructed based on macrofaunal abundance. Following the division into groups from cluster and MDS analysis, the species having the greatest contribution to this division were determined using SIMPER. In order to investigate relationships between biotic and abiotic variables, the BIO–ENV procedure was used which contrasts the station similarity matrix obtained for species abundance data via cluster analysis to the resulting matrix of Euclidean distances obtained following PCA ordination of all the possible combinations of selected environmental variables. The data to study the long term changes was taken from published papers and reports (Parulekar et al 1982; Ansari et al. 1992, 2007; Anon 1996b, 1998; 1999). Abundance biomass comparison curve (ABC curve; PRIMER 6) and the benthic opportunistic polychaete amphipod index (BOPA; Dauvin and Ruellet 2007) were used to determine the environmental status of the study area.

ANOVA and Tukey's post hoc analysis was performed to find out the significance of spatial and temporal variation on the environmental and biological parameters. The normality of the data was verified using the Kolmogorov-Smirnov test and the homogeneity of variances using the Levens' test. When data did not satisfy the assumptions of the parametric tests, the data was log transformed to achieve normality. Correlation was carried out, in order to relate the environmental and biological data (Statistica 6).

3.3 Results

3.3.1 Temporal variation of macrofauna

3.3.1.1 Macrofaunal Abundance

The macrofaunal community in the Mormugao harbour was represented by 141 taxa belonging to 10 phyla (Table 3.1). On an average polychaetes (49%) and bivalves (45%) dominated the faunal abundance. Crustaceans and other groups (Coelenterata, Nematoda, Nemertinea, Oligochaeta, Sipuncula, Phoronida, Gastropoda, Insecta and Ophiuroidae) contributed to the remaining 6% of the abundance. The dominance of polychaetes and bivalves showed seasonal variation (Fig 3.1). Polychaetes dominated during pre monsoon (82.8%) and monsoon season (92.17%) whereas bivalves dominated in post monsoon (57.7%). Mean faunal abundance was high during post monsoon (8773 ind m^{-2}) which decreased drastically to 887 ind m^{-2} in pre monsoon at all the stations (Fig 3.2). It was followed by sizeable increase to 1684 ind m^{-2} in monsoon season. Two-way ANOVA detected significant seasonal differences in macrobenthic abundance ($p<0.001$; Table 3.2). Tukeys post hoc test confirmed significantly high abundance during post monsoon. Plate 3.1-3.3 represents some of the macrobenthic fauna from the area.

The mean abundance of bivalves ranged from 3 – 5064 ind m^{-2} seen during monsoon and post monsoon, respectively. *Timoclea* (*Chioneryx*) *scabra* dominated the macrofauna in terms of abundance (43%) and ranged from 1 - 4641.65 ind m^{-2} during monsoon and post monsoon, respectively. *Paphia textile* was next in dominance among bivalves and abundance ranged from 1-204 ind m^{-2}.

The polychaete abundance was high during post monsoon (3362 ind m^{-2}) which dropped drastically in pre monsoon (735 ind m^{-2}) and increased during monsoon (1553 ind m^{-2}).

The most abundant polychaetes were *Prionospio pinnata* (7.7%), *Magelona* sp. (6.0%), *Mediomastus* sp. (5.57%), *Cossura* sp. (5.0 %) and *Tharyx* sp. (4.5%). The abundance of *P.pinnata* was higher during monsoon season (533 ind m^{-2}) and dropped during post monsoon. The minimum abundance of 15 ind m^{-2} was in pre monsoon. Abundance of *Magelona* sp. increased from monsoon (58 ind m^{-2}) to post monsoon (591 ind m^{-2}) and like all other species the abundance of *Magelona* decreased sharply during pre monsoon (36 ind m^{-2}). *Mediomastus* sp. showed a similar trend to that of *Magelona* sp. Abundance increased from 122 ind m^{-2} in monsoon to 383 ind m^{-2} in post monsoon but decreased in pre monsoon to 127 ind m^{-2}. The abundance of *Cossura* sp. was stable with high values in monsoon (210 ind m^{-2}) and marginal decrease during post monsoon (180 ind m^{-2}) and pre monsoon (187 ind m^{-2}). Abundance of *Tharyx* sp. ranged from 48 – 272 ind m^{-2}. High abundance was observed during monsoon with low values in pre monsoon season. Dominance of polychaete species showed seasonal variation with *P.pinnata* dominating in monsoon, *Magelona* sp. and *Mediomastus* sp. in post monsoon and *Cossura* sp. in pre monsoon.

Bray-Curtis cluster analysis grouped the sampling months into three groups (Fig 3.3a). The post monsoon months (Oct-Jan) formed the major group with a similarity value of 49.56% (Group I). February, March and April clustered at 62% similarity (Group II). The month of May clustered with June and July forming the third group at 53% similarity. MDS showed a similar pattern of clustering of the months (Fig. 3.3b).

The result of SIMPER analysis is summarised in Table 3.3. Group1 differed from other two groups due the complete dominance of *T.scabra* during post monsoon and accounted to >40% of the dissimilarity observed (Fig. 3.3c). The low abundance of macrofauna during pre monsoon with the dominance of *Cossura* sp. was responsible for the clustering of the pre monsoon months and its dissimilarity with other groups (Fig. 3.3 d). September did not cluster with any group (group 4) mainly due to the dominance of *P.pinnata* (1448 ind m^{-2}; Fig. 3.3e).

In general, the macrofauna was dominated by few species and most of them persisted throughout the study period. However, the abundance of some species showed marked temporal fluctuation. The first community of the area was characterized by the dominance of *P. pinnata* and *Tharyx* sp. (Fig. 3.3 e and f). A shift in the community was observed during post monsoon. This community was characterized by exceptionally high value of *T. scabra* (Fig. 3.4 c). *P. pinnata* and *Tharyx* sp. were replaced by smaller polychaetes such as, *Magelona* sp. (Fig. 3.3g) and *Mediomastus* sp (Fig.3.3 h). A change in the community was observed during the pre monsoon season with a general decline in the fauna. The community composition changes were primarily caused by drastic decline in the dominant species (e.g. *T. scabra)*. Of all the species, *Cossura* sp., dominated the community throughout the study period but was most dominant during pre monsoon season when all the other species showed a drastic decline (Fig. 3.3 d).The other species which had moderately higher abundance were *Nepthys polybranchia*, *Mediomastus* sp., *Minuspio cirrifera* and unidentified Capitellidae.

3.3.1.2 Macrofaunal Biomass

Average macrofaunal biomass was high during the post monsoon (72.07 g m^{-2}) and low during monsoon (4.27 g m^{-2}) at all the stations (Fig 3.4). Bivalvia dominated the biomass and contributed to 84.4% of the total biomass. The values ranged from 63.27-5.45 g m^{-2} (26.7±31.80 g m^{-2}) observed during post monsoon and monsoon respectively. Average polychaete biomass was high during post monsoon (2.90 g m^{-2}) and low during pre monsoon (0.96 g m^{-2}). The biomass of other groups showed a similar trend with high values of 5.08 g m^{-2} during post monsoon and low values in monsoon (0.09 g m^{-2}). Macrobenthic biomass showed significant seasonal variation ($p<0.001$). The post hoc test indicated significantly low biomass in monsoon.

3.3.1.3 Macrofaunal Diversity

Species number and species richness was high during post monsoon (75.25 and 8.39; Fig. 3.5 a) and lower during monsoon (36 and 4.9). Species richness showed significant temporal differences ($p<0.001$). Tukey's test showed that all three season differed significantly with respect to species richness with higher values in post monsoon. Species number also showed similar significant differences between stations ($p<0.001$). Evenness was higher during the pre monsoon (0.72) and lower during post monsoon (0.54; Fig. 3.5 b) at all the seven stations. Species evenness showed significant temporal variation ($p<0.001$). Mean species evenness was significantly higher during pre monsoon. Shannon-Wiener diversity was higher during pre monsoon (2.72). Diversity was 2.3 during post monsoon and 1.6 in monsoon (Fig. 3.5 c). Diversity showed significant seasonal difference ($p<0.01$).

3.3.2 Spatial variation of macrofauna

3.3.2 .1 Macrofaunal Abundance

Average macrofaunal abundance ranged from 878 -7840 ind m^{-2} (4116±2829 SD). High values were recorded at stn. 6, and low in stn. 5 (located in the channel area). Overall, polychaetes (47%) and bivalves (46%) dominated and contributed to 93% of the total abundance. Crustaceans (2%) and Nematodes (2%) made to 4% of the total faunal abundance. Species composition and dominance varied among the sampling locations. Twenty most dominant species (species which contributed to >1% of the total abundance) made to 83% of the total faunal abundance (Table 3.4). Two way ANOVA detected significant variation between stations ($p<0.05$).

Polychaetes dominated the macrofaunal abundance at all the stations except stn 4 and 7 where the bivalve was the most dominant group. Abundance of polychaete ranged from 694-4075 ind m^{-2}. As seen in table 3.4, 15 species of polychaetes were dominated and together contributed to >60% of the total polychaete fauna. Overall, *Mediomastus* sp. and *P. pinnata* were the most dominant and contributed 7% each to the total macrofaunal abundance.

As seen in table 3.4, the dominant species at stn 1 contributed to 68% of the total fauna in the location. Nematoda (8.2%), *Mediomastus* sp. (9.3%), *Terebellides stroemi* (7.5%) dominated at this station. Abundance of all the dominant species was higher during post monsoon season. *Polydora coeca* (14%) and *Mediomastus* sp. (14%) dominated at stn 2. Nematoda (9.96%), *Magelona* sp. (9%) and *Disoma orissae* (8.16%) were the other dominant taxa at stn 2. *C. scabra* dominated the fauna at stns 3, 4, 6 and 7 and made to 32.43%, 73.3%, 38.8%, and 41.7%, respectively. *Mediomastus* sp. was next in order of dominance at stn 3 (12.3%) and was followed by *Euclymene insecta* (8.17%). The other dominant species at stn 4 were *Mediomastus* sp. (5.6%) and *Axiothella obockensis* (3.4%). The channel station was completely dominated by *Cossura* sp. (16%) and *P. pinnata* (14%). At stn 6, *P. pinnata* (15.11%), *Magelona* sp. (10.52%) and *Tharyx* sp. (8.82%) were other dominant species. *Tharyx* sp (8%), *P. pinnata* (7%), *P. textile* (6.7%), *Cossura* sp. (6.6%) and were next in order of dominance at stn 7.

Ampelisca sp., *Photis* sp., *Pseudocyclaspis* sp. and *Cyathura* sp. were dominant among the crustaceans. These species occurred in all the sampling locations, however with low abundance. Abundance of *Ampelisca* sp. ranged from 1-28 ind m^{-2}. Low values were at stn. 6 (1 ind m^{-2}). Abundance of *Photis* sp. was higher at stn1 (39 ind m^{-2}) and lower at stn 7 (4 ind m^{-2}). The isopod, *Cyathura* sp. was high at stn 6 (13 ind m^{-2}) and low at stn 4 and 5 (2 ind m^{-2}). Nematoda contributed to 2% of the total macrofaunal abundance and was high at stn 1 (152 ind m^{-2}) and stn 2 (177 ind m^{-2}). Low values were seen at stn 4 (9 ind m^{-2}) and stn 5 (16 ind m^{-2}).

The abundance data of dominant species was subjected to Bray-Curtis cluster analysis and MDS (Fig.3.6). The method detected four groups and reliability of the data was seen from the low stress values (0.01). Stns 1- 2 clustered together with 74.4% similarity. Group 2 consisted of stns 3 and 4 and showed 74.8% similarity. The harbour stations (stn 6 and 7) with 83.76% similarity formed the third group. MDS ordination showed a marked demarcation between the inner, outer and the channel station (Fig.3.6b).

SIMPER analysis was performed based on the results of MDS to find out, which species accounted for the similarity within the group and differences between groups (Table 3.5). The following species contributed to the similarity: Group I – *Mediomastus* sp. (22 %), Nematoda (19.4%; Fig. 3.6 c and d) and *N. polybranchia* (8.2%). Group II- *T. scabra* (53 %), *Mediomastus* sp. (18%), *Cossura* sp. (6.8 %; Fig. 3.6 e and f). Group III- *T. scabra* (47 %), *Tharyx* sp. (9 %), *P.pinnata* (7.8%; Fig.3.6 g and h).

3.3.2.2 Macrofaunal Biomass

Macrofaunal biomass showed similar pattern to that of abundance with high value of 78.78 gm^{-2} recorded at stn 4 (Fig. 3.4) and low value of 4.47 gm^{-2} at stn 5. The biomass of polychaete ranged from 1.54 (stn 1 and 2) to 4.85 g m^{-2} (stn 6). The biomass of bivalve was higher at stn 4 (63.54 g m^{-2}) and lower at stn 5 (1.79 g m^{-2}). The values for all other taxa were generally higher at stn 7 (14.7) and lower at stn 4 (0.07 g m^{-2}). The values showed significant variation between stations ($p<0.001$) largely due higher mean values at stn 4 and 7.

3.3.2.3 Macrofaunal species diversity

In terms of species, Polychaeta dominated with 70 species and accounted for 50% of the total identified taxa. In terms of number of species, the class Bivalvia was next in order of dominance with 15 sp. and the family Veneridae dominated the group with 8 species. Amphipoda (13 species), Gastropoda (9 species), Isopoda (4 species), Cumacea (3 species), Decapoda (5 species) were other dominant groups. Species number was higher at stn. 3 with 99 taxa and lower number of taxa (61) were observed at stn 5. Generally, the species richness was lower in the harbor area (stn 6) 6.9 and higher richness of 12 was at stn 2. It showed significant spatial variation ($p<0.001$) and significantly lower mean value was at stn 5. Shannon-Wiener diversity (*H'*) ranged from 1.36- 3.5 with minimum and maximum values being at stn 4 and stn1, respectively. Species evenness was lower at stn 4 (0.59) and higher at stn 1 (0.81; Fig.3.5). The variation between the stations was not significant ($p<0.05$). The values for species diversity also varied significantly ($p<0.01$) between stations.

3.3.3 Correlation between faunal abundance and environmental variables

The correlation of macorbenthic parameters (abundance, biomass, species diversity) and the environmental factor is summarised in table 3.6. The results revealed that macrofaunal abundance showed significant positive relationship with bottom water chl *a* and phaeopigment, and dissolved oxygen, however it was negatively correlated with BOD. Biomass showed a similar significant correlation with phaeoigment, chl *a* and DO. Species richness showed a strong positive correlation with DO, OC, sand and negative with silt. Species diversity was positively correlated with salinity and NO_3 (Fig 3.7-3.8). Evenness was positively correlated with bottom water salinity ($r= 0.61$) and bottom and surface water temperature. Table 3.7 gives the correlation of some of the dominant species and environmental parameters. *C. scabra* was positively correlated with DO ($r=0.48$; $p<0.05$). *Mediomastus* sp. showed significant positive correlation with surface and bottom water oxygen ($r= 0.59$ and 0.49 respectively), sand ($r=0.8$, $p<0.05$) and negative with silt ($r= -0.80$) and clay ($r= -0.59$). *P.pinnata* was strongly related to water chl *a* ($r=0.58$; $p<0.05$) and sediment chl *a* ($r=0.49$; $p<0.05$). *M .cirrifera* was related to the sediment texture and showed positive relation with sand ($r=0.64$, $p<0.05$) and negative with silt ($r= -0.62$) and clay ($r= -0.57$). *T. stroemi* was positively correlated with sediment. OC ($r= 0.58$).

Overall, the BIOENV analyses revealed a weak correlation between environmental parameters and benthic data ($\rho = 0.37$; Table 3.8). Of all the parameters silt showed highest correlation ($\rho = 0.37$). The other parameters were sediment chl *a*, DO, sand, BOD and NO_3 provide the best overall correlations (Table 3.8).

3.3.4 Long term changes in the benthic community

3.3.4.1 The Macrofaunal Community

The macrofauna of the area was compared with the earlier data (1972, 1982, 1996, 1998, 1999 and 2001-02) to see changes in the community (Table 3.9). This was attempted mainly because the long-term measures of species composition provide important indicators of ecosystem functioning, the status of biotic resources and anthropogenic impacts on the community. The study carried out in 1972-73 is the first detail sampling of the estuary and hence considered as the baseline data(Parulekar et al. 1980).

Total abundance, biomass and species number increased by 61%, 11% and 65% respectively. The increase observed was perhaps due to deposit feeding opportunistic polychaete which contributed to >35% of species number and >45% of the abundance. Crustaceans which are considered to be sensitive to pollution accounted to only 2% of the total density and 21% of total species. In 1972-73, crustaceans were the second dominant group.

The carnivorous *Dioptra neopolitana*, *Glycera alba* and the deposit feeding *P. pinnata* were the dominant species during 1972-73. However, *P. pinnata* showed dominance during 1981 (Ansari et al. 1986) and was the most dominant species during 1991 (Ansari 1995). *P. pinnata* abundance showed a substantial increase from 1972 (283 ind m^{-2}) to 1991 (329 ind m^{-2}). In the present study, *P. pinnata* contributed to 8% of the total macrofaunal abundance and comprised 14% of the total polychaete density. The dominance of *P. pinnata* over the other species was perhaps its ability to utilize the higher organic matter and rapidly recolonize (Pearson and Rosneberg 1978; Rouse and Pleijel 2001) Ansari et al. (1994) described the benthic fauna of Mormugao harbour and reported Nereidae to be the most widespread family followed by Cirratulidae. Compared to the previous studies, 62 polychaete species are reported from the area for the 'first time'. However, some of the species reported earlier such as *Dioptra neopolitana*, *Marphysa* sp. were not observed during the present study.

The dominance of the area by opportunistic polychaete species and reduction of important bivalve resources indicate influence of the harbour activity. The increase in opportunistic species could be due to increased organic carbon through various activities. The activities in the harbour region results in increase turbidity, which could have resulted in decreased filter feeding species like bivalves.

3.3.4.2 Abundance biomass comparison curve (ABC curve)

ABC (abundance biomass comparison) curves proposed by Warwick (1986) were used to investigate community perturbation at the study sites through the years. ABC plots were constructed based on the published data and reports. The W statistic involves summing the differences between the ranked cumulative percentages of abundance and biomass values (Clarke 1990). In this statistic, W takes values in the range (-1, 1), with W at +1 for even abundance across species but biomass dominated by a single species, which is an undisturbed community, and W at -1 in the converse case.

The data for ABC was estimated for 1972, 1982, 1996, 1998, 1999, 2001-02 data (Fig 3.9). Interpretation of ABC curve suggests that the baseline data (1972) showed undisturbed condition (Fig. 3.9a). A similar condition was observed during the 1982 study. In the 1996 study, the biomass and abundance showed a crossing at many points (Fig 3.9 c). However change in ABC curve was first observed in 1999 samples (Fig. 3.9 e). In the present study, the ABC curve showed the dominance of biomass curve over the abundance curve. This was further confirmed by the partial curve, which showed the crossing of the abundance curve and dominance at several point indicating stress condition in the area (Fig 3.9 g-h).

3.3.4.3 Polychaete: Amphipod ratio (P: A)

The polychaete amphipod ratio has been proposed by Dauvin and Ruellet (2007) to evaluate the health status of a habitat. P: A values 0 indicate unpolluted condition and 0.3 indicates a grossly polluted condition. P: A ratio was highest at stn 6 (0.24) and lowest was recorded at stn 4 (0.14; Fig 3.10 a). Seasonally, the ratio did not show significant variation and was highest during pre monsoon (0.22) and low during post monsoon (0.17; Fig. 3.10b).

3.4 DISCUSSION

3.4.1 Temporal Variability of macrofauna

The macrofaunal community showed a marked seasonality ($p<0.001$) during the study. The abundance, biomass and diversity peaked during post monsoon and falls drastically during pre`monsoon. The high abundance of macrofauna during post monsoon (Fig.3.2) was predominantly due to the successful recruitment of small bivalve, *C. scabra*. It was remarkable to note that inspite of extensive macrobenthic sampling conducted by previous workers (Parulekar et al. 1980; Ansari et al. 1986; Ansari et al. 1994; Harkantra and Rodrigues 2003), *T. scabra* has not been reported from this area. It was astonishing to see that *T. scabra* dominated the area with 43 % of the total faunal abundance. However, the density of *T. scabra* decreased drastically during pre monsoon. The possible reason for drastic decrease in the bivalve abundance during pre monsoon was due to the enhanced harbour activities (vessel movement and maintenance dredging). The shipping activities are generally at its peak during fare season *i.e.* pre monsoon. During monsoon, the shipping activities are reduced due to the rough weather conditions. The increased harbour activities after monsoon also increases the sediment load and other contaminants. Further, the temperature and salinity also showed an increase.

Bivalves are filter feeders and the increased suspended load in pre monsoon may have caused the clogging of their gills leading to death. Consequently, it is possible that the high abundance of juvenile *T.scabra* observed in the harbour area during post monsoon may have been from the adult population established outside the harbor area. In disturbed areas, the dominant recolonizing factor is the supply of larvae, juvenile and/or adults coming from the farther location (Chollett and Bone 2007).In fact, the tide dominated Zuari River may facilitate wide dispersion of *T. scabra* larvae. Most marine benthic invertebrates have planktonic larvae, which last for four to eight weeks (Shanks et al. 2003) and duration of planktonic phase greatly affects the potential spread of larvae from their parents (Bohank 1999). Shanks et al (2003) estimated the dispersal distances of larvae with planktonic duration of four to eight weeks to be about 50 to 100 km. Predation, food availability, disease, competition, abiotic factors are also know to play an important role in the survival of juvenile marine invertebrates (rev. Gosselin and Quina 1997).

Similarly, the abundance of most macrofauna decreased rapidly after the settlement and leveled at a value unrelated to the peak settler density. The abundance, biomass and species number showed 90% reduction in pre monsoon. Therefore, increased harbour activities along with extreme environmental conditions during the pre monsoon season can cause considerable stress to the organisms and only the species tolerant to this high stress can survive. The most dominant macrofauna during pre monsoon season was *Cossura* sp. Other species were *Tharyx* sp., *M. cirrifera*, *N. polybranchia* and unidentified Capitellidae. The adults and larvae of these polychaete species have remarkable tolerance to elevated hydrocarbon and other pollutants that are toxic to most other fauna (Levin et al. 1996; Chandler et al. 1997; Holmer et al. 1997). Nevertheless, their dominance in contaminated sediments was due to higher pre capita rates of recruitment and adult survival compared to more sensitive taxa (Levin et al. 1996).

The monsoon samples were characterized by early colonizing species such as *P.pinnata* and *Tharyx* sp. Among the polychaetes, spionid family is known to increase in number after the disturbance since their life history allows them to rapidly colonize disturbed areas (Hylleberg and Nateewathana 1991; Blake and Arnofsky 1999; Rouse and Pleijel 2001). Majority of the species belonging to this family has small body size and during their reproduction they produce several broods in a year and once established, grow fast. The early maturity in spionid ensures rapid increase in their population (Grassle and Grassle 1974).

Species number, evenness and diversity showed significant temporal variability ($p<0.001$). Species number followed a similar pattern to macrofaunal biomass with higher values in post monsoon and low values during monsoon. Species diversity and evenness was higher during pre monsoon. Shannon-Wiener diversity was low during monsoon whereas evenness was low during post monsoon. Low evenness during post monsoon was expected as faunal abundance was completely dominated by *T. scabra*, *Mediomastus* sp. and *Magelona* sp.

Therefore, it was seen that the community of Mormugao harbour did not follow the general pattern in seasonal variation, typical of tropical estuaries i.e decrease during monsoon and increase during post and pre monsoon. In tropical estuaries, decrease in abundance during monsoon with substantial increase during the post- and pre monsoon is understandable when the conditions have stabilized (Pannikar 1969; Parulekar et al. 1980; Ingole and Parulekar 1998). The negative effects of monsoonal rain on the benthic fauna were attributed to increased levels of sediment disturbance (Alongi 1990; Ingole and Parulekar 1998). The increased salinity during pre monsoon triggers the reproduction in most of the benthic fauna (Bemvenuti 1987, 1997; Ingole and Parulekar 1998). Majority of the taxa, especially the polychaete in pre monsoon were adults and microscopic inspection of random specimens indicated that, most of them were carrying eggs. The macrofaunal community during post monsoon was dominated by juvenile population suggesting the recolonisation of the area after the cessation of monsoon. The seasonal variability thus, was influenced by recruitment process. The importance of recruitment in influencing the macrofaunal community is evident from augmented biomass and abundance during different months (Fig 3.2 and 3.4). The abundance peaked in October and the fauna was comprised mostly of juvenile forms. The biomass peaked after two months and the fauna was comprised of adult specimens. The low abundance of macrofauna and dominance of opportunistic polychaete species during pre monsoon indicate the influence of harbour activities in structuring the macrobenthic community in the area.

3.4.2 Spatial variability of macrofauna

The macrofaunal abundance and biomass was low in the navigation channel (stn 5; Fig 3.2), apparently due to the continuous disturbance by vessel movements. Moreover, annual maintenance dredging carried out to deepen the channel further affects the fauna. Cluster and MDS ordination plots were also able to discriminate the study location into three groups. The stations in the harbour and channel were separated from the stations situated outside the harbor, indicating a clear difference in benthic community within the study area. SIMPER, confirmed the results that the variations observed between the locations were largely due to the dominance of different species during different season.

Higher faunal abundance was at stn 6 (7840 ind m^{-2}), located in the harbour. The area was dominated by few opportunistic polychaete species (51.62%) such as *P.pinnata*, *Tharyx* sp., *Magelona* sp., Capitellidae and *Mediomastus* sp. and the bivalve, *T. scabra* (38.87%). However, although in very high abundance, *C. scabra* was seen only during post monsoon (8784 ind m^{-2}) which decreased by 99% in pre monsoon.

The polychaete community in the outer harbour was represented by *Mediomastus* sp., *P. coeca* and *A. obockensis*. Further, compared to the inner harbour, rare and sensitive species occurred in some of the outer harbour stations. *Mediomastus* sp. dominates in area of moderate disturbance and high energy environment outside the Mar del Plata harbour in Argentina (Rivero et al. 2005). In fact, species belonging to the genus *Mediomastus* flourish in habitat with moderate amount of organic matter with total absence in area of high organic pollution (Pearson and Rosenberg 1978). Higher abundance of *T. stroemi* was observed in the outer stations (Table 3.4, chapter 3) and was found in low abundance or absent in the harbour. This species is known to have large ecological flexibility essential for adapting under stress conditions (Stoykov and Uzunova 2001). It was not reported earlier from the area, and hence needs further detailed monitoring in future. Further, compared to the inner harbour, rare and sensitive species belonging to Syllidae, Poecilochaetidae and Phyllodocidae families occurred in some of the outer harbour stations. Species belonging to Syllidae are highly sensitive to pollution or any kind of stress, showing decrease in species number and individual or complete disappearance (Giangrande et al. 2004). However, opportunistic species occur in this group but are very rare. *Syllis krohnii* and *Syllis* sp. occurred in the harbour region however in low density. *S. krohnii* and *S. gracilis* are among the few opportunistic syllid species (Giangrande et al. 2004). The outer harbour stations are close to the estuarine mouth where the maximum disturbance is observed in an estuarine area. Therefore the outer stations cannot fully represent undisturbed communities, as it was thought prior to sampling, firstly because of its location and secondly the sediment texture was sandy silt and showed seasonal variation. This may be the reason for dominance of opportunistic deposit feeding species, reflecting the more dynamic and less stable nature of the area.

Though the abundance was higher in the inner harbour, species number and richness was higher in the outer harbour. However, the low diversity and evenness was at stn. 4

(outer harbor) largely due to the dominance of *T. scabra* which made to 73% of the faunal abundance.

Polychaete dominated the species diversity during the entire study period. Family Spionidae, Paranoidea, Capitellidae and Cirratulidae showed high abundance and diversity. Species belonging to these families have been identified as opportunistic or early colonizer (Grassle and Grassle 1974; Pearson and Rosenberg 1978). They can quickly respond to open or unexploited habitats by either a high reproduction rate and or a high dispersal ability (Grassle and Grassle 1974). These species are motile subsurface or surface deposit feeders (Fauchald and Jumars 1979).

It is generally accepted that soft- sediment communities are dominated by opportunistic species (*r* selected) characterized by high reproduction rate and genetic variation following heavy disturbance events (Rhoads et al. 1978; Giangrande 1997). Therefore opportunistic species are more stress tolerant (Jernelöv and Rosenberg 1976). As most of the species recovered from the Mormugao harbour were opportunistic deposit feeders and hence it appears that the entire area is characterized by environmental instability and, thus, by stressful conditions. *P.pinnata*, *Cossura* sp., *Magelona* sp., unidentified Capitellidae, Cirratulidae and *Tharyx* sp. were dominant in the area (Table 3.4). These species have been established as pollution indicators (Grassle and Grassle 1974; Pearson and Rosenberg 1978). Overall, the results agree with the studies done in other harbours, which were also dominated by few opportunistic polychaete species (Table 3.8). High levels of OC may have contributed to the high abundance of opportunistic species in the inner harbour. But the low diversity in inner harbour reflects the negative effect of increased organic levels. The present finding agrees very well with other studies where maximum diversity was observed in an area with moderate OC with a decrease in diversity with increased OC (Magni 2003; Albayrak et al. 2006). Further, the area was well oxygenated and the main effect contaminants are usually due to the lack of oxygen (Estacio et al. 1997; Fig. 3.9). Therefore, though the area had dominance of opportunistic species, it did not lead to defaunation of the community.

Crustaceans were found with low diversity and only during the post monsoon season. Most crustaceans are sensitive to the disturbance and are considered as slow colonizers (Gomez-Gesteira and Dauvin 2000). Thus, the macrobenthic community of the study area appears to be composed of tolerant polychaete species, able to withstand continuously disturbing environmental conditions.

The BIOENV analyses showed a weak correlation between environmental parameters and biotic data ($\rho = 0.37$; Table 3.8). Snelgrove and Butman (1994) concluded that the complexity of soft-sediment communities may defy any simple paradigm with regard to any single factor in controlling their settlement and colonization. Of all the parameters, silt showed highest correlation ($\rho = 0.37$). Other parameters with a relatively good combination was given with silt, chl *a*, DO, sand, BOD and NO_3 (Table 3.9). The PCA of environmental parameters also confirms their importance in the study area (Table 2.8 and Fig. 2.5). During, the present study, the increased phytoplankton production reflected by high chl *a* content in water and sediments by the end of monsoon, was followed by increase in faunal abundance during post monsoon. Macrobenthic abundance and biomass was positively correlated with chl *a*, phaeopigment and OC (Fig. 3.7), indicating that availability of quality food may be the important factors maintaining high benthic standing stock.

Further, the biological community did not show significant relation with sediment and water contaminants. Chemical concentration in environmental parameters is not always an accurate predicator of biological and ecological effects (Burton and Scott 1992). Hence, the use of benthos in environmental monitoring has an advantage as it can integrate conditions over a period of time rather than reflecting condition during the time of sampling. The lack of any significant relationship between the biotic and abiotic parameters may be due to the low bioavailability of the contaminants or the concentrations of the contaminant are too low to induce any effect on the community. Further, bioavailability of contaminants depends on bioturbation, salinity, temperature, redox, pH (Bryan and Langston 1992; Walsh and O'Halloran 1997). On the other hand, organic matter is also known to be an important factor controlling the abundance of trace metals (Rubio et al. 2000). The reason for the low values of the contaminants in the area may be due to the hydrodynamic nature of the study area. The flushing by tides results in the quick dispersion of the contaminants into the sea. Further, heavy runoff of the Zuari estuary during the SW monsoon increases the flushing in the area by ten folds (Shetye et al. 2007). In addition, the harbour activities are considerably reduced during the monsoon period.

3.4.3 Long term changes in the benthic community

An attempt was made to evaluate the long-term change in the benthic diversity and community structure in the area by examining previous data. However, the comparison had its limitations as the earlier studies were often based on limited samplings and species identified were not fully presented. Further, very few studies have pursued the long term impact of anthropogenic activities on the benthic community (Pearson 1975; Raman 1995). Most studies on the impact of harbour activities are based on a single sampling (Guerra-García and García-Gómez 2004; Rivero et al. 2005).

The earlier studies revealed that polychaete was the most diverse and abundant group and was true for the present study. However, notable change was observed in the community composition. The carnivorous, *D. neopolitana* and *G.alba* were replaced and dominated by opportunistic, *P.pinnata*. A similar shift was observed by Raman (1995) in Visakhapatnam harbour. The carnivorous *D. neopolitana* and *Nereis glandicincta* were replaced by the opportunistic, *Capitella capitata*. Ansari et al (1994) reported that Nereidae dominated the Mormugao harbour community. Further, carnivorous species belonging to the family Glyceridae, Goniadidae, Eunicidae, Nereidae were recorded in low abundance and mostly in the outer station. Of the 71 identified polychaete species, 62 are reported for the first time from the area. Moreover, 43% of the species were deposit feeders and dominated in terms of abundance. *Mediomastus* sp., which dominated the polychaete community of the area, was not reported previously. Other species present in higher number and not reported earlier are *Tharyx* sp., *A. obockensis*, *A. catherina*, *Polydora coeca*, *Pseudopolydora kempi*, *Jasmineira* sp. Increase in deposit feeding polychaetes in the area can be attributed to the enhanced organic load. Average organic carbon value which was 1 % in 1972 (Parulekar et al. 1980) increased to 2% during the present study. The values were particularly higher in the harbour stations. *D. neopolitana* feeds on algae, sponges, bryozoans and crustaceans and *G. alba* prefers motile preys, such as small polychaetes and amphipods compared to sessile and tube dwelling forms (rev. Fauchald and Jumars 1979).

In the earlier studies Crustacean was the second dominant group. However, crustaceans were replaced by bivalves in the present case. Further, crustaceans, specially the amphipods show high sensitivity to pollution as the population decreased from highly polluted habitats (Dauvin and Ruellet 2006). The change in food availability must have resulted in decrease of carnivorous forms. Studies on the effects of pollutants on soft-sediment fauna have shown a general trend towards reduced faunal and trophic diversity, larger proportion of short-lived opportunistic taxa with smaller body sizes and fewer deep-dwelling species in contaminated sediments (Pearson and Rosenberg 1978; Warwick and Clarke 1993; Rakocinski et al. 1997). The changed environmental conditions therefore, favoured opportunistic polychaete species to flourish.

In pollution monitoring studies, the ABC approach is highly recommended by Warwick (1986), who stated that in 22 cases of comparison between species biomass and number curves, only one case has given a false impression of the pollution status of the benthic community. Warwick et al (1986) suggested that the abundance/ biomass comparison is a suitably abbreviated descriptor of the state of pollution and its effect on marine macrobenthos. The advantage of distribution plots such as the k-dominance curve is that the distribution of species abundances among individuals can be compared at the same time, since they have different units of measurements. Warwick (1986) gave three situations under which an area can be classified as unpolluted, polluted and extremely polluted. According to this explanation, if the k-dominance curve for biomass of an area dominates over the abundance curve then the area may be termed as unpolluted. If the biomass and density proceed close to each other and the biomass curve crosses the abundance curve one or more times, then the area may be termed as polluted. If the ABC curve of an area showed the dominance of abundance curve over the biomass, the benthic community is dominated by large number of a very few species, then the area may be termed as extremely polluted.

The ABC curve analysed for data from 1972 to 2002, indicated the community was undisturbed during 1972 as the biomass curve dominate over the abundance. The abundance curve began to dominate the biomass curve in 1996 and was the case in the present study. The present data was also subjected to partial dominance curve. Since a problem with cumulative nature of ABC curve is that visual information presented is over-dependent on the single most dominant species. In case of genuine disturbance, the pattern of ABC curve will be unaffected by successive removal of the one or two most dominant species in terms of the abundance or biomass, and hence Clarke (1990) recommended the use of partial dominance curve. The partial dominance computes the dominance of the second ranked species over the reminder. The partial dominance curves for undisturbed communities will have the biomass curve above the abundance curve throughout its length. The abundance curve is much smoother than the biomass curve, showing slight and steady decline before the inevitable final rise. Under polluted conditions, the abundance curve is above the biomass curve in places, and the abundance curve becomes much more variable. This implies that pollution effects are not just seen in changes to a few dominant species but pervade all the species in the community. When the partial curve was used for the present data, it showed the abundance curve crossing and above the biomass at many places. The community was dominated by small sized opportunistic polychaete species except during post monsoon when the small bivalve, *T. scabra* dominated the abundance and biomass.

The P: A ratio ranged from 0.14 at stn 4 to 0.24 (stn 6). P: A values 0 indicate unpolluted condition and 0.3 indicates a grossly polluted condition. The high values were recorded in the harbour region and stations in close vicinity of the harbour. Seasonally the values did not show significant variation with highest values during the pre monsoon season. The high values during pre monsoon indicate stress condition which corresponds to the increase harbour activity during this season. The community during this period is represented by opportunistic polychaete species.

The studies on the impact of development on the estuarine ecosystem are generally confounding as natural variability is usually superimposed on the anthropogenic disturbance (Solis-Weiss et al. 2004; Morrisey et al. 1992; Rakocinski 1997). Further, smaller scale heterogeneity is maintained by complex pattern of recruitment, physical disturbance and biotic interaction (Barry and Dayton 1991; Thrush et al. 1996). Stress associated with pollutant exacerbates this spatial variability by increasing the abundance of individual taxa or through changes in the taxonomic composition of samples from within and among affected sites (Warwick and Clarke 1993) as was the case in the present study.

The harbour area is usually characterized by high contaminants and reduced oxygen level. This high stress is enough to drastically reduce the fauna or cause defaunation but remarkably the fauna of Mormugao harbour is high, in contrast to many harbours around the world. Further, the contaminants studied in the area were within the limit prescribed for the harbour area. One possible explanation for this may be the hydrodynamic nature of the area that flushes the contaminants out and maintains the oxygen levels of the area. However, the effect of the harbour activities was seen, as the community was represented and dominated by opportunistic polychaete species. Comparison with earlier data and multivariate analysis (Cluster, MDS, ABC and PA ratio) also revealed the change in community from the baseline study.

3.5 Conclusion

The macrofaunal community showed high abundance, biomass and species number during post monsoon, which was mainly due to the recruitment process. The pre monsoon is considered to be stable period; however during the present study the macrofaunal abundance was lowest during this period. Further, *T.scabra* which dominated the area during post monsoon showed >90% reduction during pre monsoon. Most of the other macrofaunal species showed a similar trend. During pre monsoon the fauna in the area was dominated by opportunistic deposit feeding polychaete species. Therefore macrofaunal community in the harbour did not follow the general pattern of seasonal variability typical of tropical estuaries. Even though, the possible reason for abrupt changes in population could not be ascertained from the data, harbour activities which peaks during pre monsoon could undoubtedly reduce the established population of macrofauna.

The present result however does not allow us to directly link between anthropogenic activities and observed pattern in the fauna. Nevertheless, there are several evidences which suggest a strong relationship between the macrobenthic community and harbour activities. Macrobenthic community clearly demarcated the outer and the inner harbour stations, which was not clear from the water and sediment variables. Further, the dominance of opportunistic polychaete species and reduction of important bivalves indicate the influence of the harbour activity on the benthic community. The increase in opportunistic species could be due to the increased organic carbon from various harbour activities.

Comparison with earlier data revealed that important changes have occurred in the community and the changes have been brought about by the increase in sedentary, detritivor and/or deposit feeding species on the one hand and the reduction in predatory forms on the other hand. Further, out of the 71 polychaete species identified 62 were reported for the first time from the area. This may be due to extensive sampling carried during the present study. Since the Mormugao port is one of the busiest port along the west coast of India and handles 7% of the total traffic of the country, the possibility of invasive species cannot be ruled out. Therefore it is possible that some of the species recorded may be invasive. However due to lack of detailed baseline data of the harbour macrofaunal community, it is difficult to confirm the same. Thus, measures of species composition provide important indicators of ecosystem function, the status of biotic resources and anthropogenic impacts on the community.

Table 3.1 Seasonal variation of macrobenthic taxa in the study area, 2003-2004 (+ : present; - : absent)

Taxa	Monsoon	Post monsoon	Pre monsoon
Obelia colony #1	+	+	+
Obelia colony #2	+	+	+
Hydroid	+	+	+
Zooanthus	-	+	-
Nematoda	+	+	+
Nemertenia	+	+	+
Polychaeta			
Phyllodoce malmgreni	-	+	+
Phyllodoce madeirensis	-	+	-
Phyllodoce sp.	-	+	-
Eteone sp.	-	+	-
Podarke sp.	-	+	+
Syllis cornuta	-	+	-
Syllis krohnii	+	+	+
Syllis sp.	-	+	-
Sphaerosyllis sp.	-	-	-
Exogene sp.	+	+	+
Odontosyllis sp.	+	-	-
Sthenelais sp.	-	+	-
Harmothoe spp.	+	+	+
Hesione spp.	+	-	-
Ancistrasyllis constricta	+	+	+
Ancistrasyllis groelandica	+	+	+
Nephtys polybranchia	+	+	+
Nereis sp.	-	+	+
Drilonereis macrocephala	-	+	-
Glycera alba.	+	+	+
Glycera longipinns	+	+	+
Glycinde oligodon	-	+	+
Gylcinde spp.	+	+	+
Goniadides spp.	+	+	+
Goniada hexadentes	-	+	+
Goniada sp.	-	+	+
Pisione oesterdii	+	+	+
Tharyx spp.	+	+	+
Chaetozone sp. 1	+	+	+
Chaetozone sp. 2	+	+	+
Capitilla sp.	-	+	-
Mediomastus sp.	+	+	+
Heteromastus sp.	-	+	+
Neomediomastus sp.	-	+	-
Notomastus sp.	-	+	+
Dasybranchus sp.	-	+	-
Capitellidae	+	+	+
Euclymene insecta	+	+	+

Contd..

Taxa	Monsoon	Post monsoon	Pre monsoon
Axiothella obockensis	-	+	+
Prionospio pinnata	+	+	+
P. krusadensis	-	-	+
Polydora spp.	-	+	-
Polydora ciliate	+	+	+
P. coeca	+	+	+
P. antennata	-	+	+
Pseudopolydora kempi	-	+	+
Minuspio cirrifera	+	+	+
Magelona sp.	+	+	+
Poecilochaetus serpens	-	+	+
Phyllochaetopterus sp.	-	+	+
Disoma orissae	+	+	-
Dorvillea manadapmae	+	+	+
Lumbriconereis laterelii	+	+	+
Lumbriconereis spp.	+	+	-
Eunice indica	-	+	+
Dioptra clapaderi	-	+	-
Onuphis eremite	+	+	+
O. dibranchiate	-	+	-
Onuphis sp.	-	+	-
Terebellides stroemi	+	+	+
Sabellaria cementaria	-	+	-
Jasimineira sp.	-	+	+
Saccocirrus sp.	-	+	-
Sternapsis scutata	+	+	+
Scoloplos spp.	+	+	+
Aricidea catherina	+	+	+
Aricidea multiantennata	-	-	+
Aricidea sps.	+	-	-
Aricidea assimilis	-	+	-
Paradoneis armata	+	+	-
Levinsenia sp.	+	+	+
Cossura sp.	+	+	+
Armandia lanceolata	-	+	-
Unidentified 1	+	+	-
Oligocheata	+	+	+
Sipuncula	-	+	-
Phoronida	-	+	-
Bivalvia			
Nuculana sp.	-	-	+
Modiolous sp.	-	+	-
Cardita bicolor	+	+	+
Venerupis sp.	-	+	-
Sunetta sp.	-	+	-

Contd..

Taxa	Monsoon	Post monsoon	Pre monsoon
Paphia textile	+	+	+
Sunetta sp.	-	+	-
Pitar erycina	-	-	+
Timoclea scabra	+	+	+
Venus sp.	-	+	-
Gafrarium sp.	-	+	-
Dosinia sp.	-	+	+
Mactra sp.	-	+	-
Tellina sp.	-	+	+
Solenidae	-	+	-
Gastropoda			
Cavolina sp.	+	-	+
Monilea sp.	-	+	-
Marginella sp.	-	+	-
Calyptraea sp.	-	-	+
Chelicera sp.	-	+	-
Olivia sp.	-	+	+
Muricidea sp.	-	+	-
Thais sp.	-	+	+
Surcula sp.	-	-	+
Unidentified	+	-	-
Amphipoda			
Ampelisca sp.	+	+	+
Hyale sp.	-	+	-
Cheirocratus sp.	-	+	-
Maera sp.	-	+	-
Monoculodes sp.	-	+	+
Westwoodilla sp.	+	+	-
Ampithoe sp.	-	+	-
Pallasia sp.	-	+	-
Photis sp.	+	+	+
Gammaropsis sp.	-	+	-
Corophium sp.	+	+	-
Podocerus sp.	-	+	-
Caprella sp.	-	+	-
Unidentified	+	-	+
Tanidacea	+	+	+
Cumacea			
Cyclaspis sp.	+	+	-
Pseudocyclaspis sp.	-	+	+
Unidentfied cumacea	+	+	+
Isopoda			
Cyathura sp.	+	+	+
Accalthura sp.	-	+	-
			Contd..

Taxa	Monsoon	Post monsoon	Pre monsoon
Vulvifera sp.	-	+	-
Unidentified	-	-	+
Ostracoda	+	+	+
Decapoda			
Decapoda larvae	+	-	-
Brachyuran	-	-	+
Thalasinid shrimp	-	+	-
Carridean shrimp	-	-	+
Eupagurus sp.	+	-	-
Penaidae	+	-	+
Harpacticoida	-	-	+
Pycnogonida	+	-	-
Ophiuridae	-	+	+
Insect larvae	-	+	-
Fish	-	-	+

Table 3.2
Two-way ANOVA result showing showing the variation of benthic data between stations (7), seasons (3) and their interaction. F statistic and probability (p).

		F	P
Abundance	Season	18.07	0.000
	Station	2.60	0.031
	S*S	1.67	0.108
Biomass	Season	41.27	0.000
	Station	7.01	0.000
	S*S	4.25	0.000
Species number	Season	58.92	0.000
	Station	5.23	0.000
	S*S	1.80	0.067
Species richness	Season	42.91	0.000
	Station	6.03	0.000
	S*S	1.91	0.050
Species Evenness	Season	7.96	0.001
	Station	1.33	0.258
	S*S	1.97	0.043
Species diversity	Season	6.97	0.002
	Station	3.14	0.009
	S*S	2.25	0.019

Table 3.3
SIMPER analysis based on group obtained from cluster and MDS ordination showing the species that contributed to the differences among the groups. Av. Abund: average abundance; Av. Diss: Average dissimilarity; Contrib: Contribution

Av dissimilarity 78.32

	Group 1	**Group 2**			
Species	**Av. Abund**	**Av. Abund**	**Av. Diss**	**Contrib%**	**Cum.%**
T. scabra	4641.66	77.32	37.35	47.69	47.69
Mediomastus sp.	382.93	151.3	4.57	5.84	53.53
Magelona sp.	591.17	43.65	4.29	5.48	59
Paphia textile	203.58	29.28	2.73	3.49	62.49
Prionospio pinnata	322.23	13.67	2.53	3.23	65.72
Axiothella obockensis	159.23	3.51	2.27	2.9	68.62
Cossura sp.	180.06	211.43	2.03	2.59	71.2

Av dissimilarity 87.81

	Group 1	**Group 3**			
Species	**Av. Abund**	**Av. Abund**	**Av. Diss**	**Contrib %**	**Cum.%**
T. scabra	4641.66	14.9	39.09	44.52	44.52
Mediomastus sp.	382.93	57.65	6.12	6.97	51.49
Magelona sp.	591.17	31.79	4.59	5.23	56.72
Paphia textile	203.58	0.41	3.44	3.92	60.64
Prionospio pinnata	322.23	57.09	2.71	3.08	63.72
Axiothella obockensis	159.23	0.35	2.46	2.81	66.53
Terebellides stroemi	127.28	0	2.13	2.43	68.96

Av dissimilarity 78.73

	Group 4	**Group 1**			
Species	**Av. Abund**	**Av. Abund**	**Av. Diss**	**Contrib %**	**Cum.%**
T. scabra	3.16	4641.66	31.59	40.12	40.12
Prionospio pinnata	1447.95	322.23	12.43	15.79	55.91
Tharyx spp.	649.03	194.6	5.21	6.62	62.53
Magelona sp.	94.67	591.17	3	3.81	66.34
Mediomastus sp.	248.78	382.93	2.41	3.07	69.41
Paphia textile	1.05	203.58	2.07	2.63	72.04
Cossura sp.	326.09	180.06	1.89	2.4	74.43

Contd.......

Table 3.4
Percent composition of dominant species in the study area.

	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 7
T. scabra	3.46	2.35	32.43	73.34	1.86	38.88	41.75
Mediomastus sp.	9.34	14.24	12.31	5.63	5.32	3.59	5.34
P. pinnata	4.60	3.05	4.65	2.13	14.03	15.12	6.93
Cossura sp.	2.94	4.57	4.64	2.18	16.07	5.92	6.62
Paphia textile	0.09	0.73	0.13	0.18	0.00	2.50	6.76
Magelona sp.	0.90	9.09	2.26	0.59	0.80	10.52	5.00
Tharyx sp.	1.03	0.77	2.59	0.26	1.31	8.82	8.04
N. polybranchia	3.79	3.63	3.14	0.52	7.87	1.19	2.02
Polydora coeca	2.94	14.31	1.02	0.39	0.40	0.07	0.02
T. stroemi	7.53	1.87	2.28	0.22	4.92	0.08	0.00
M. cirrifera	3.03	2.73	2.32	0.51	2.62	1.46	1.50
Jasmineira sp.	3.84	0.76	1.05	0.23	6.78	0.00	0.00
Capitellidae	0.40	0.27	0.90	0.24	1.35	3.83	4.75
Chaetozone sp. 1	6.51	0.69	0.99	0.32	1.06	0.68	1.07
Euclymene insecta	0.03	0.04	8.17	0.06	0.00	0.10	0.25
Axiothella obockensis	3.02	1.69	1.21	3.44	0.87	0.24	0.00
Disoma orissae	0.00	8.17	0.02	0.03	0.00	0.01	0.13
Nematoda	8.25	9.97	2.40	0.13	1.45	1.79	1.10
Modiolous sp.	4.88	0.48	0.95	1.04	0.76	0.00	0.00
Photis sp.	1.90	0.42	0.45	0.38	3.43	0.23	0.08
Others	31.52	20.17	16.09	8.18	29.1	4.97	8.64

Table 3.5 Contd.......

Av dissimilarity 76

	Group 1	Group 4				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
T. scabra	57.57	2644.61	31.08	21.43	40.89	40.89
P.pinnata	72.8	656.28	6.51	1.82	8.56	49.45
Tharyx spp.	16.39	490.99	5.66	10.64	7.45	56.9
Magelona sp.	96.89	587.72	5.36	1.39	7.05	63.95
Cossura sp.	72.46	374.08	3.62	14.42	4.76	68.71
P. textile	7.87	272.49	3.45	2.12	4.54	73.25
Capitellidae	6.02	256.54	3.07	10.43	4.05	77.29
Polydora coeca	145.09	3.45	1.79	1.33	2.35	79.64

Av dissimilarity 49

	Group 2	Group 4				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
T. scabra	3534.33	2644.61	18.57	2.27	37.66	37.66
Magelona sp.	55.56	587.72	4.21	1.47	8.54	46.2
P. pinnata	148.94	656.28	3.98	1.35	8.07	54.27
Tharyx sp..	47.86	490.99	3.66	4.81	7.42	61.7
P. textile	8.87	272.49	2.37	2.05	4.8	66.5
Capitellidae	22.93	256.54	1.99	5.82	4.04	70.54
Cossura sp.	152.45	374.08	1.82	4.35	3.7	74.23
Mediomastus sp.	427.24	254.75	1.54	2.39	3.13	77.36
E. insecta	155.3	9.76	1.53	0.87	3.11	80.47
A.obockensisi	147.77	8.47	1.06	1.31	2.16	82.62

Av dissimilarity 83.7

	Group 3	Group 4				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
T. scabra	17.07 2	644.61	36.22	88.04	43.26 43	0.26
Magelona sp.	7.03	587.72	7.36	1.6	8.79 52	0.04
P. pinnata	109.45	656.28	6.84	1.4	8.17 60	0.22
Tharyx spp.	11.04	490.99	6.56	13.92	7.83 68	0.05
P. textile	0	272.49	4.12	1.67	4.92 72	0.97
Capitellidae	10.04	256.54	3.48	6.68	4.15 77	0.12
Cossura sp.	125.91	374.08	3.38	10.93	4.04 81	0.16
Mediomastus sp.	45.28	254.75	3	4.13	3.58 84	0.74

Table 3.6
Pearson's Correlations Coefficient of environmental parameters and Benthic components (Values in bold are significant at $p < 0.05$)

	Abundance	Biomass	Sp. richness	Diversity	Evenness
SS	0.11	0.29	0.26	0.34	0.43
BS	-0.04	0.12	0.34	0.53	**0.61**
ST	-0.34	-0.21	-0.18	0.19	**0.55**
BT	-0.34	-0.22	-0.19	0.19	**0.55**
S pH	0.39	0.38	0.52	0.39	0.14
B pH	0.14	0.18	0.36	0.41	0.30
S NO_2	-0.05	0.11	0.12	0.30	0.43
B NO_2	-0.39	-0.25	-0.18	0.23	**0.64**
S NO_3	0.19	0.31	0.60	**0.53**	0.24
B NO_3	0.32	0.46	0.62	0.44	0.13
S PO_4	-0.21	-0.27	-0.48	-0.43	-0.30
B PO_4	-0.07	-0.22	-0.31	-0.38	-0.37
S Phaeo	0.46	0.37	0.26	-0.17	-0.39
B Phaeo	**0.75**	**0.66**	0.26	-0.41	**-0.80**
S Chl *a*	0.45	0.17	0.22	-0.19	-0.45
B Chl *a*	**0.69**	**0.52**	0.14	-0.48	**-0.81**
S DO	**0.57**	**0.54**	**0.62**	0.16	-0.22
B DO	0.30	0.35	**0.56**	0.35	0.04
S BOD	-0.33	-0.23	-0.37	-0.07	0.22
B BOD	**-0.62**	-0.50	-0.50	-0.02	0.47
Sed Chl *a*	0.45	0.29	0.34	0.04	-0.18
OC	0.33	0.31	**0.52**	0.37	0.16
Sand	0.46	0.37	**0.68**	0.38	-0.13
Silt	-0.45	-0.37	**-0.70**	-0.38	0.18
Clay	-0.43	-0.33	-0.47	-0.30	-0.06

Table 3.7
Pearson's Correlation of dominant species and important environmental parameters (Values in bold are significant at $p < 0.05$; N=18)

	Mediomastus sp.	*P.pinnata*	*M. cirrifera*	*Magelona sp.*	*T.stroemi*	*Cossura sp.*	*T. scab*
SChl *a*	0.17	**0.58**	-0.03	0.26	-0.11	0.16	0.23
BChl *a*	0.08	0.34	-0.15	0.16	-0.17	0.13	0.29
SDO	**0.59**	0.08	0.39	0.29	0.45	-0.11	**0.48**
BDO	**0.49**	-0.01	0.40	0.20	0.31	0.09	0.26
Sed. Chl *a*	0.30	**0.49**	0.42	0.30	0.41	0.09	0.26
Sed. OC	0.28	0.00	0.43	0.13	**0.58**	-0.08	0.19
Sand	**0.80**	0.25	**0.64**	0.16	0.28	0.08	0.38
Silt	**-0.80**	-0.20	**-0.62**	-0.16	-0.28	-0.06	-0.39
Clay	**-0.59**	-0.42	**-0.57**	-0.13	-0.22	-0.17	-0.26

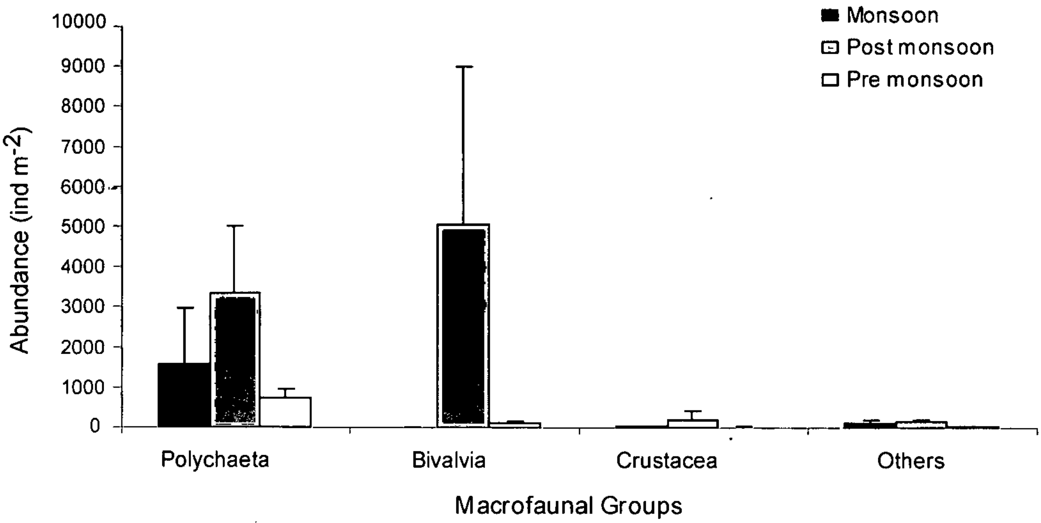


Fig 3.1 Seasonal variation (±SD) of macrofaunal group abundnace in the study area.

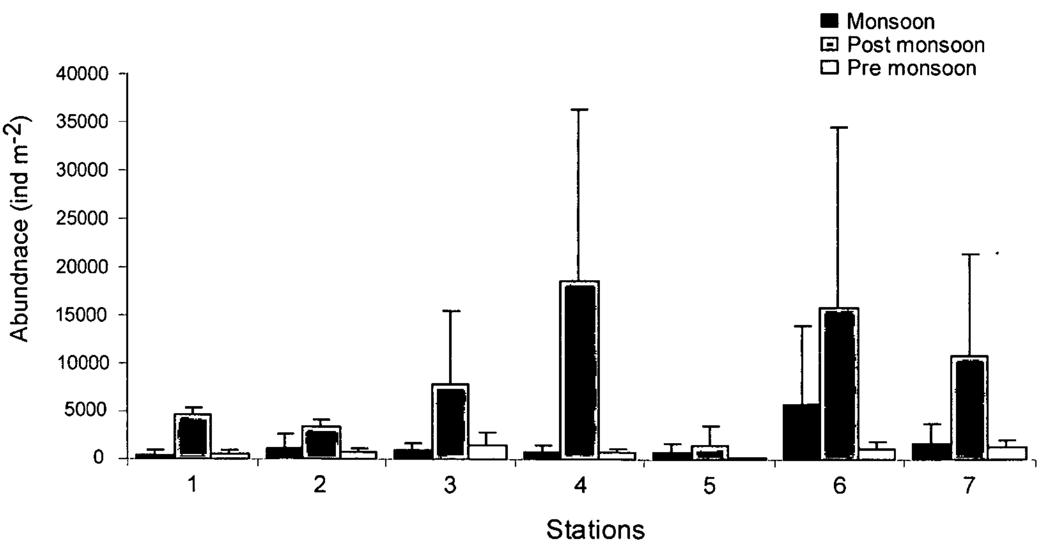


Fig 3.2 Seasonal variation (±SD) in macrofaunal abundance in the study area.

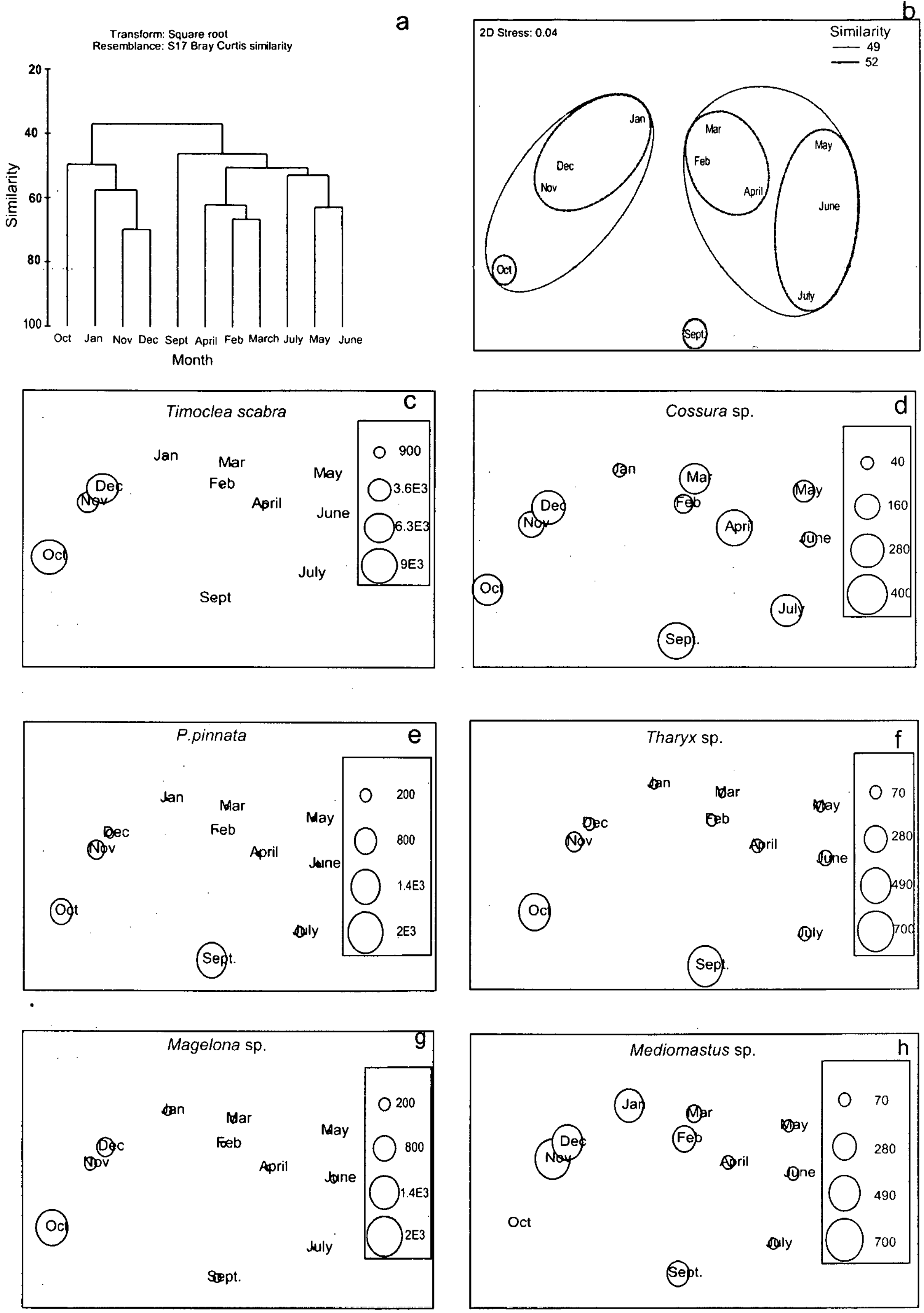


Fig 3.3 Bray-Curtis cluster (a) and MDS (b) based on the monthly species abundnace. Bubble p
showing the monthly variation in the abdundance of dominant species (c-h).

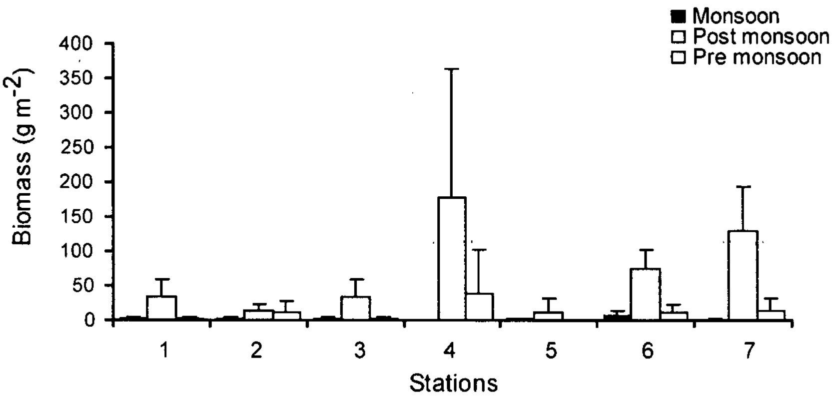


Fig 3.4 Seasonal variation (±SD) in macrofaunal biomass in the study area

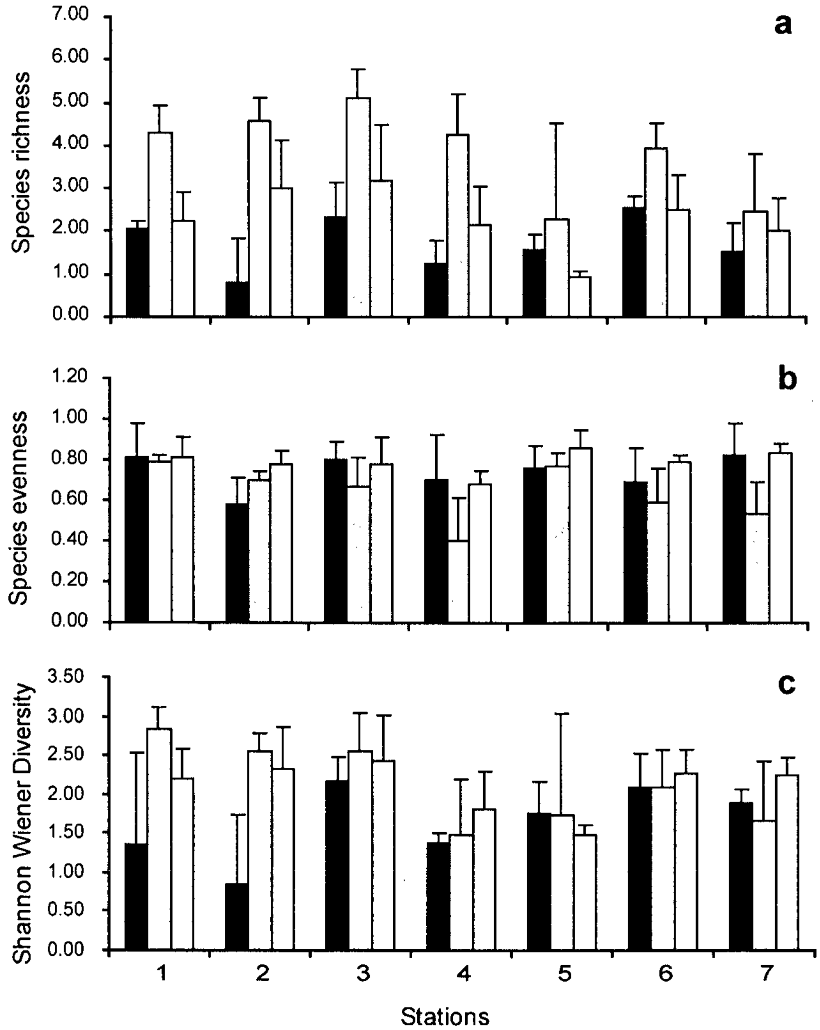


Fig 3.5 Seasonal variation (±SD) of macrofaunal species richness(a) species evenness(b) and species diversity(c)

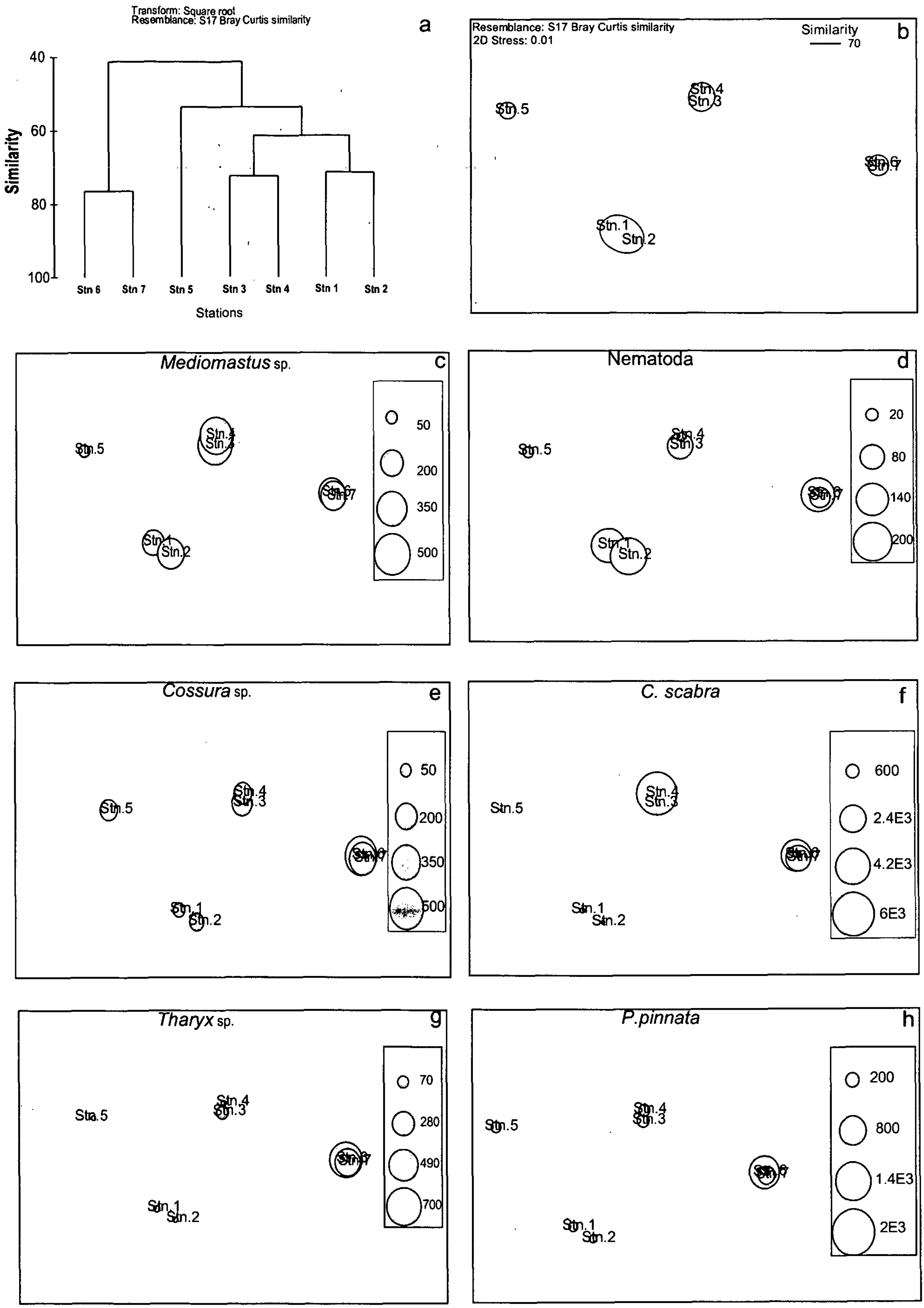


Fig 3.6 Bray Curtis cluster (a) and MDS ordination(b) based on macrofaunal species abundance. Bubble plot showing the variation in the abudnace of the dominant species (c-h).

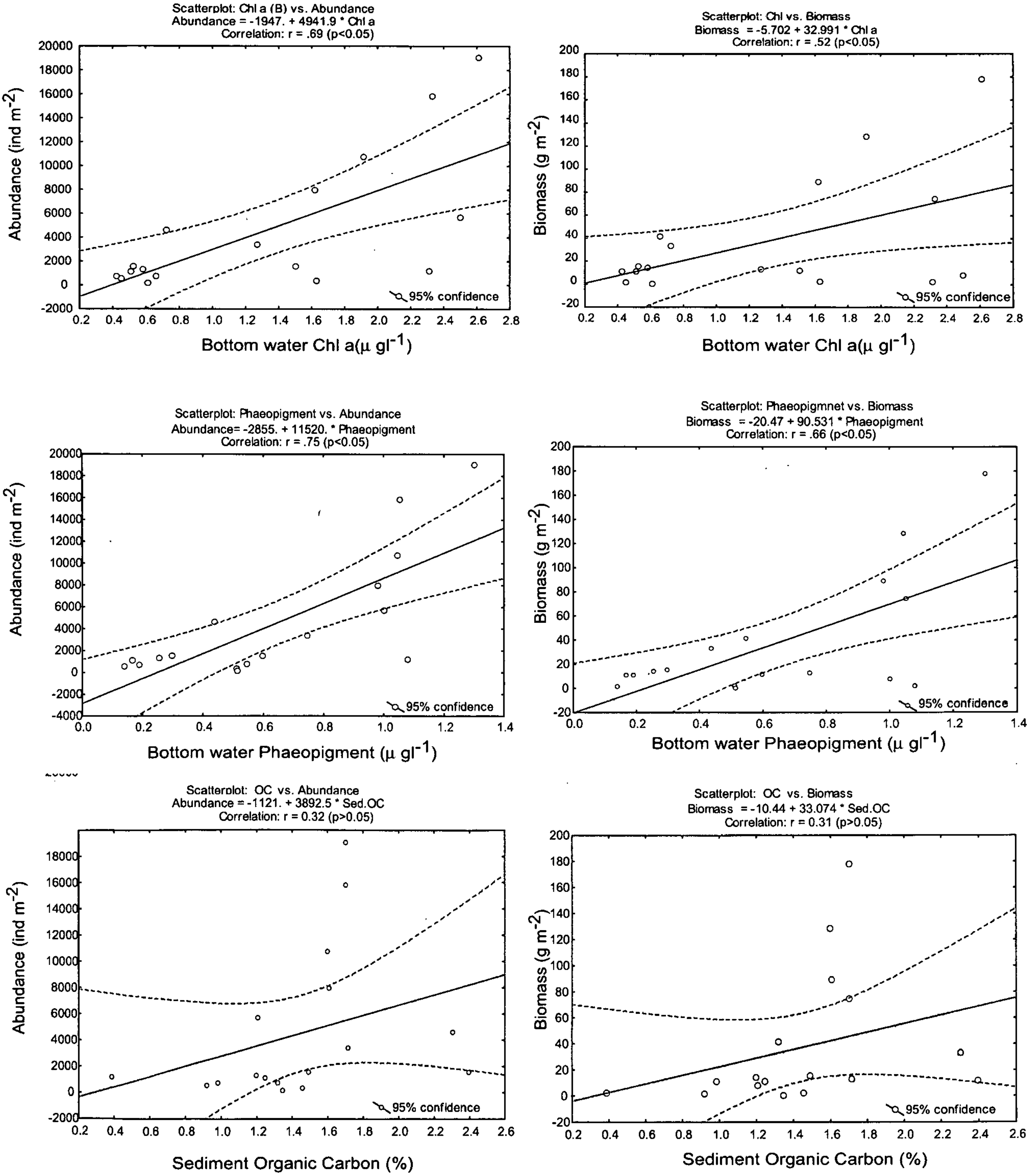


Fig 3.7 Correlation of abundance and biomass with Chl a,phaeopigment and organic carbon

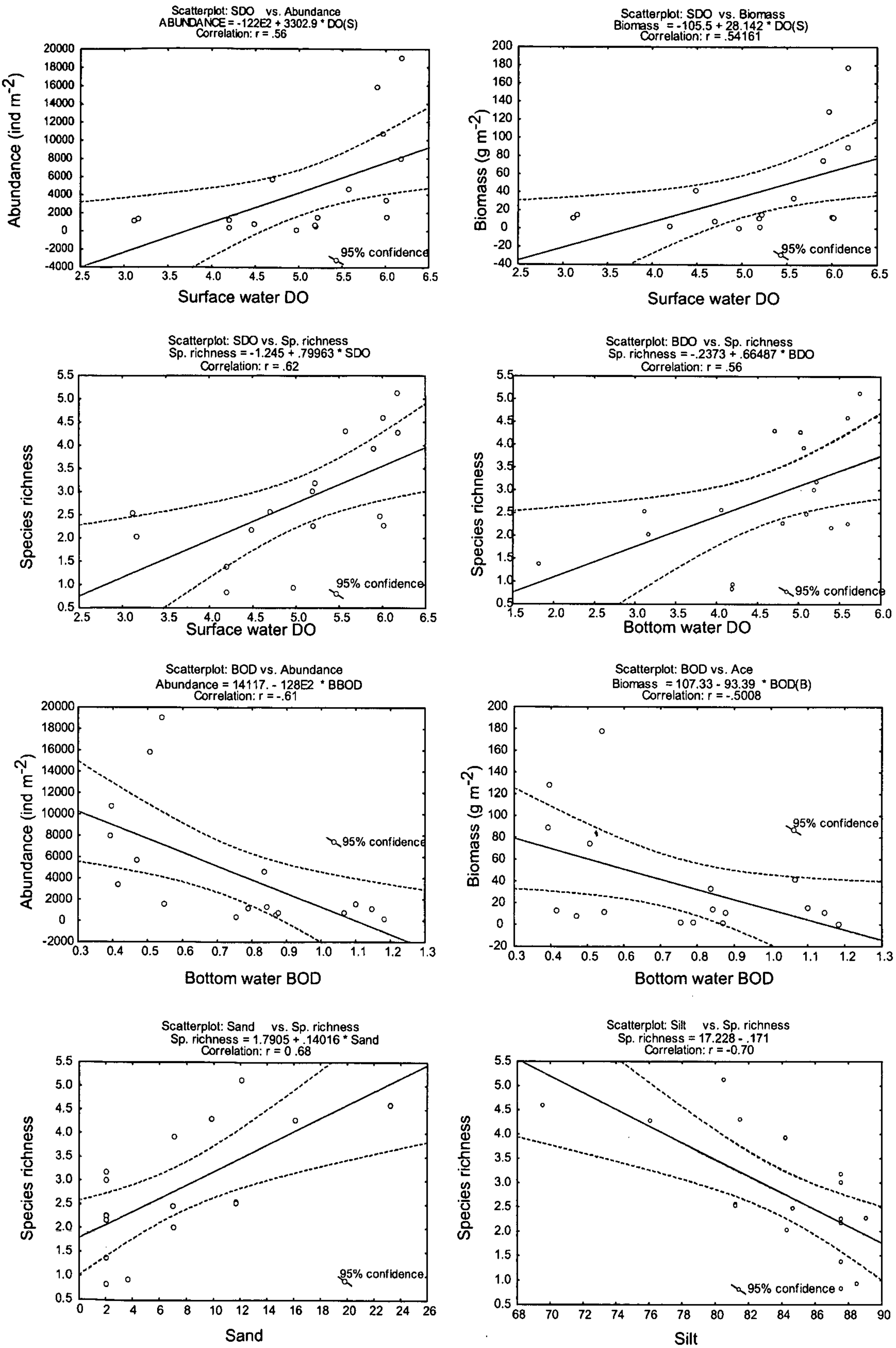


Fig 3.8 Correlation of abundance, biomass and species richness with DO, BOD with enviromental parameters

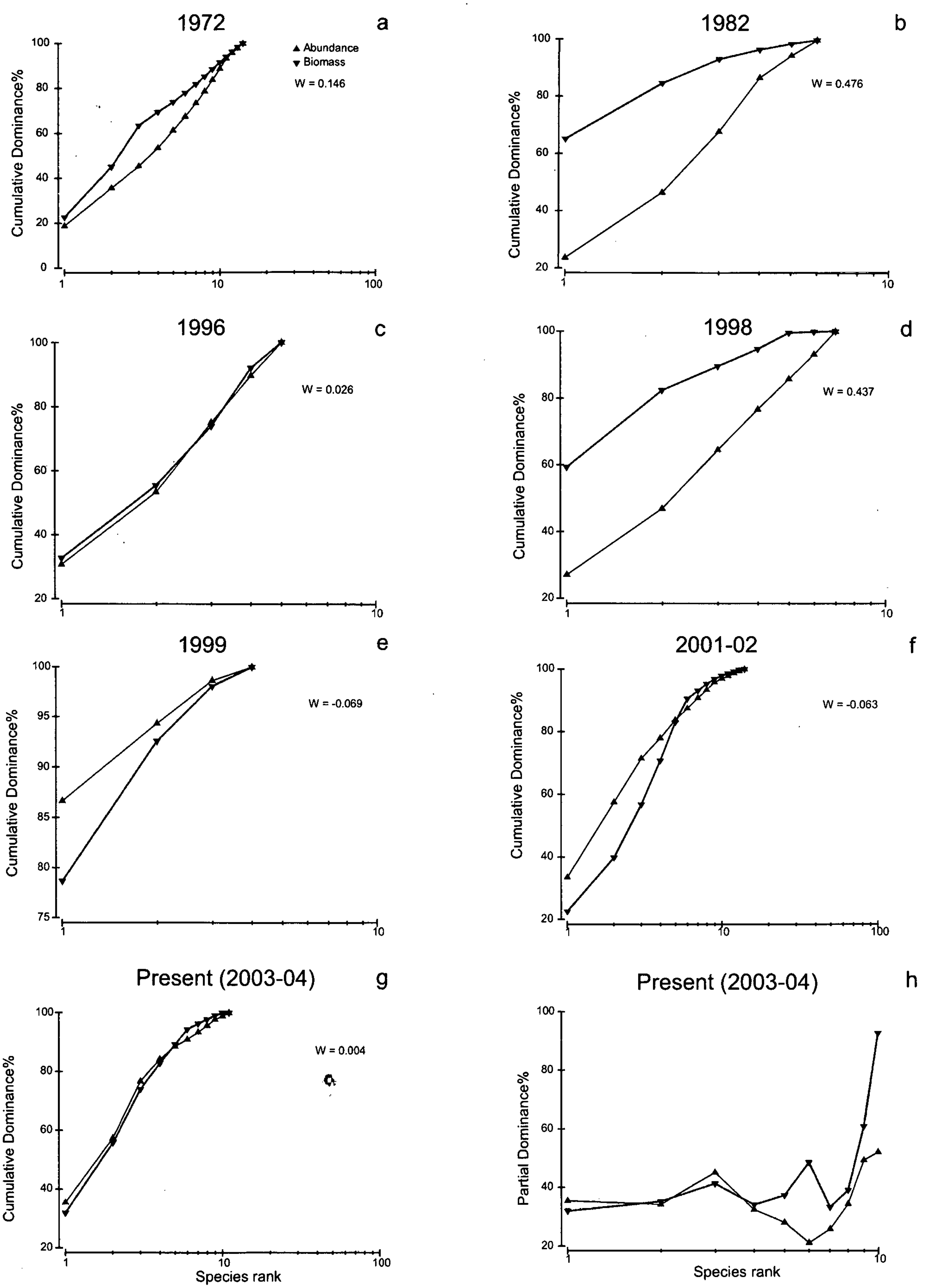


Fig 3.9 Comparison of cumulative ABC curve for 1972-2003(a-g) and partial dominance curve for 2003-4 (f)

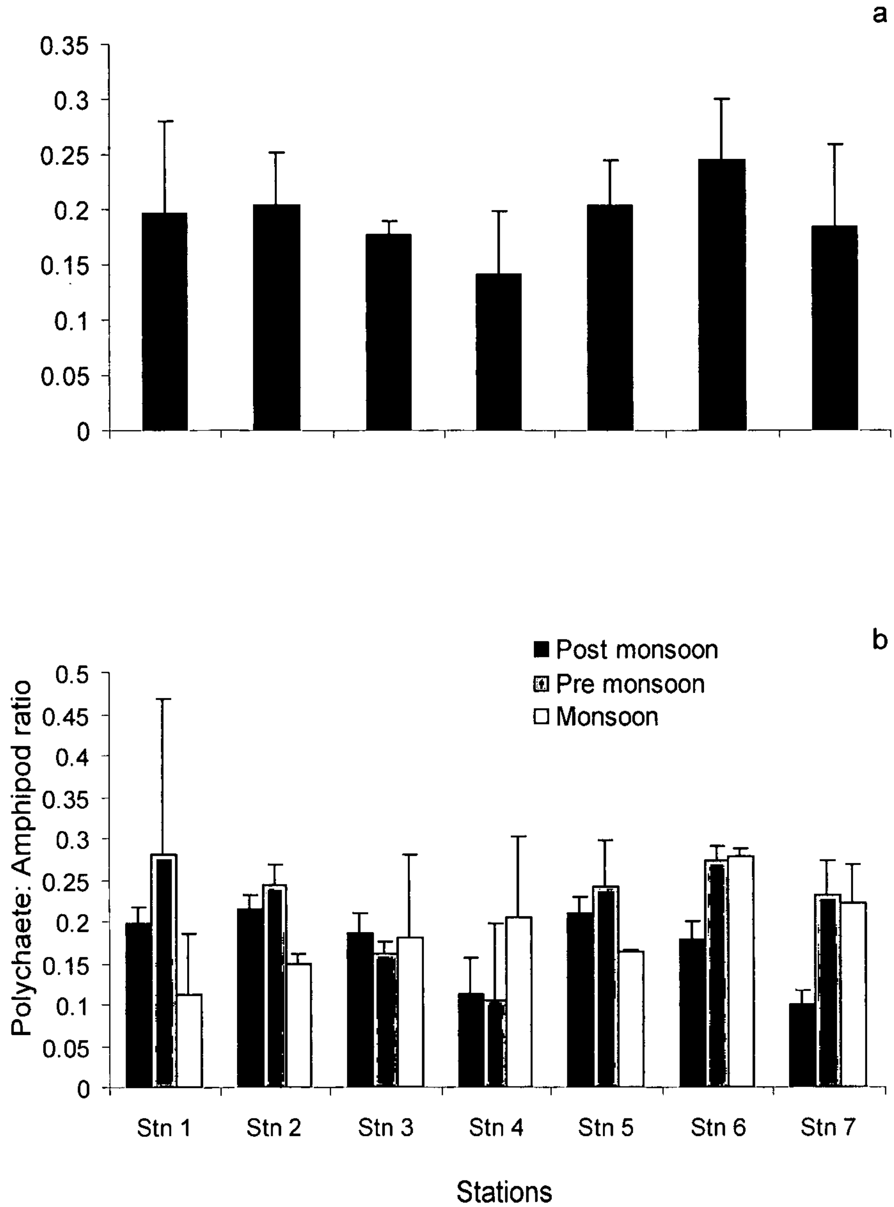


Fig.3.10 Polychaete amphipoda ratio at the seven stations (a) and seasonal variation (±SD) in the study area (b).

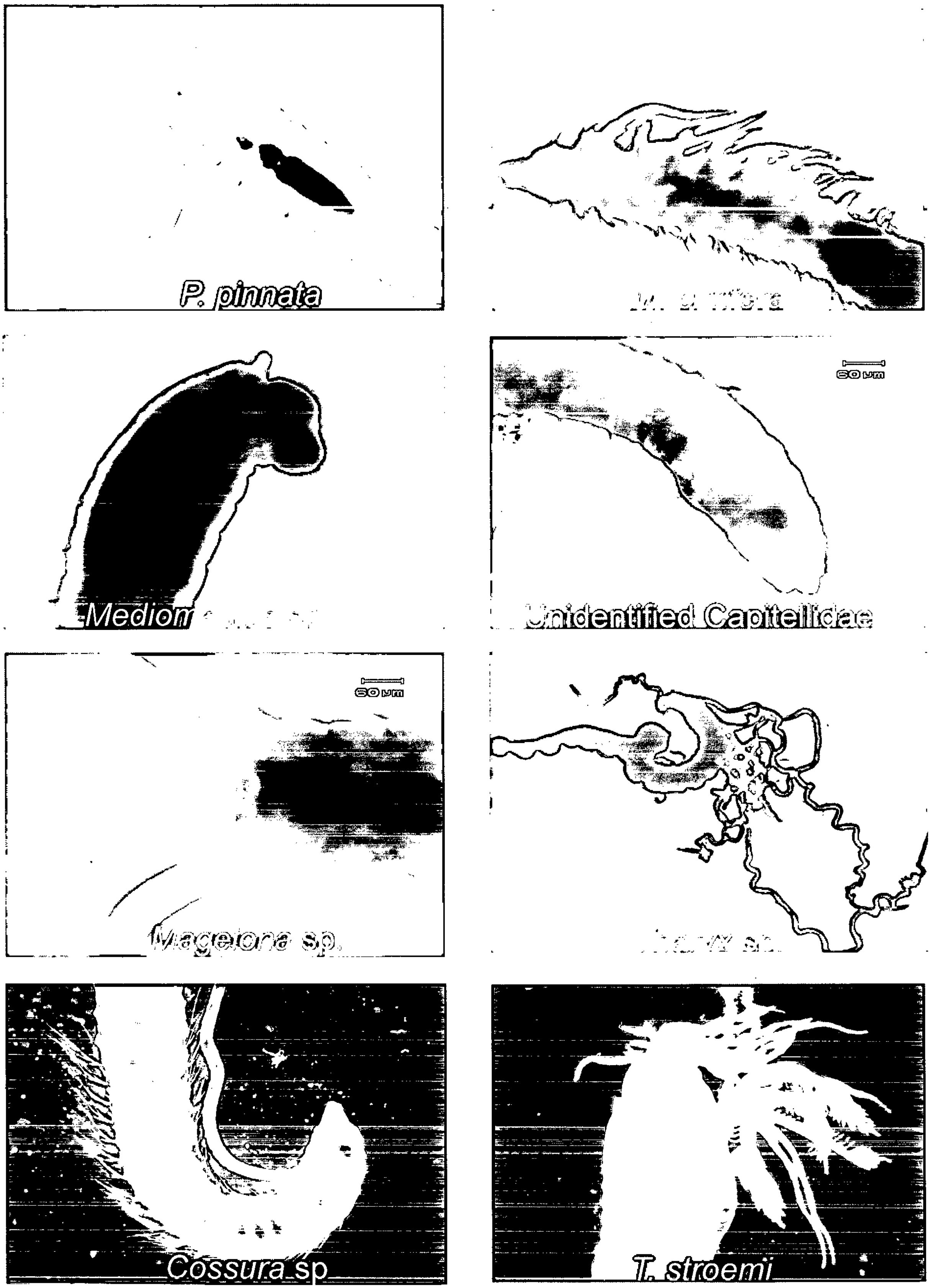


Plate 3.1 Some of the dominant polychaete species of Mormugao Harbour

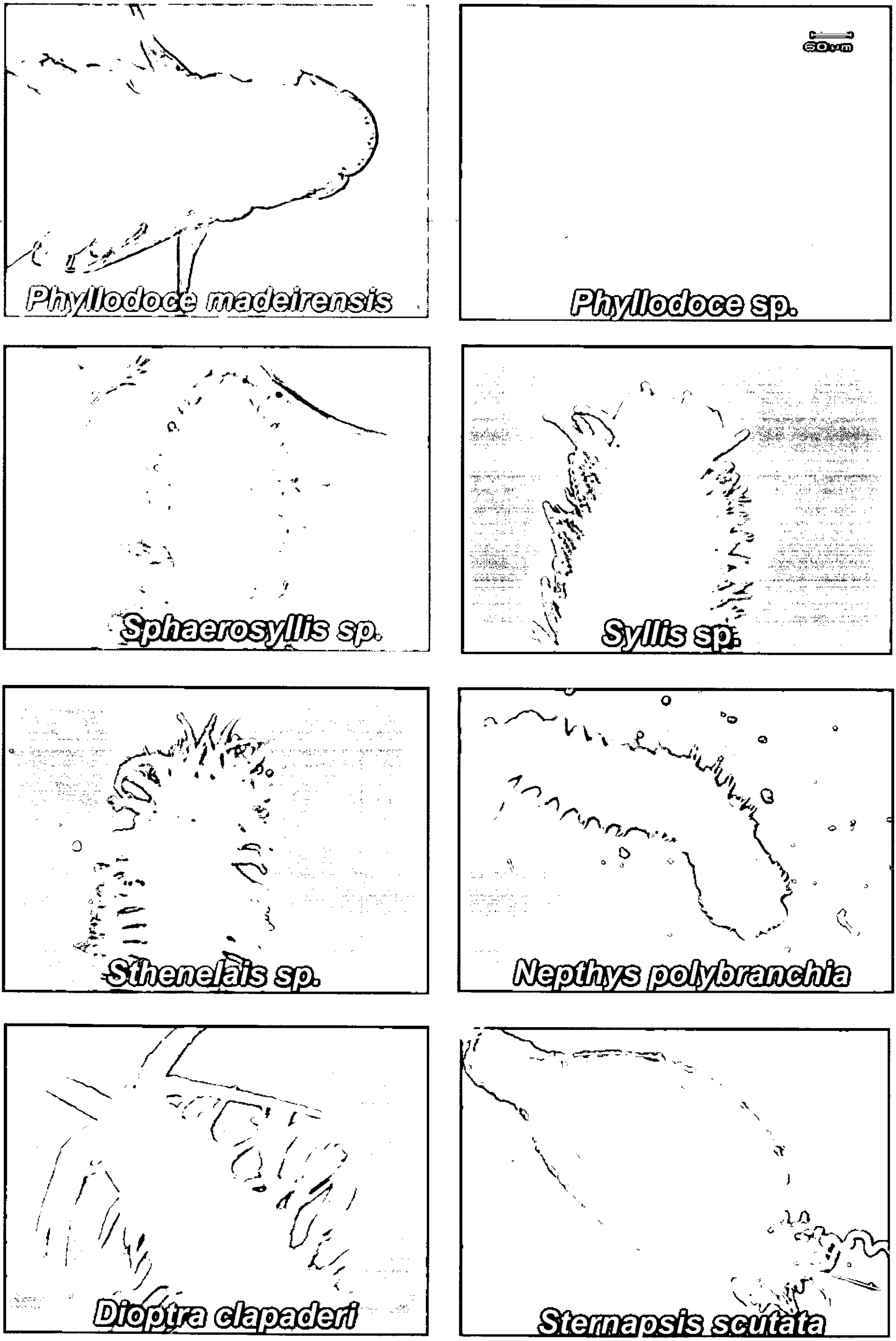


Plate 3.2 Polychaetes of Mormugao harbour

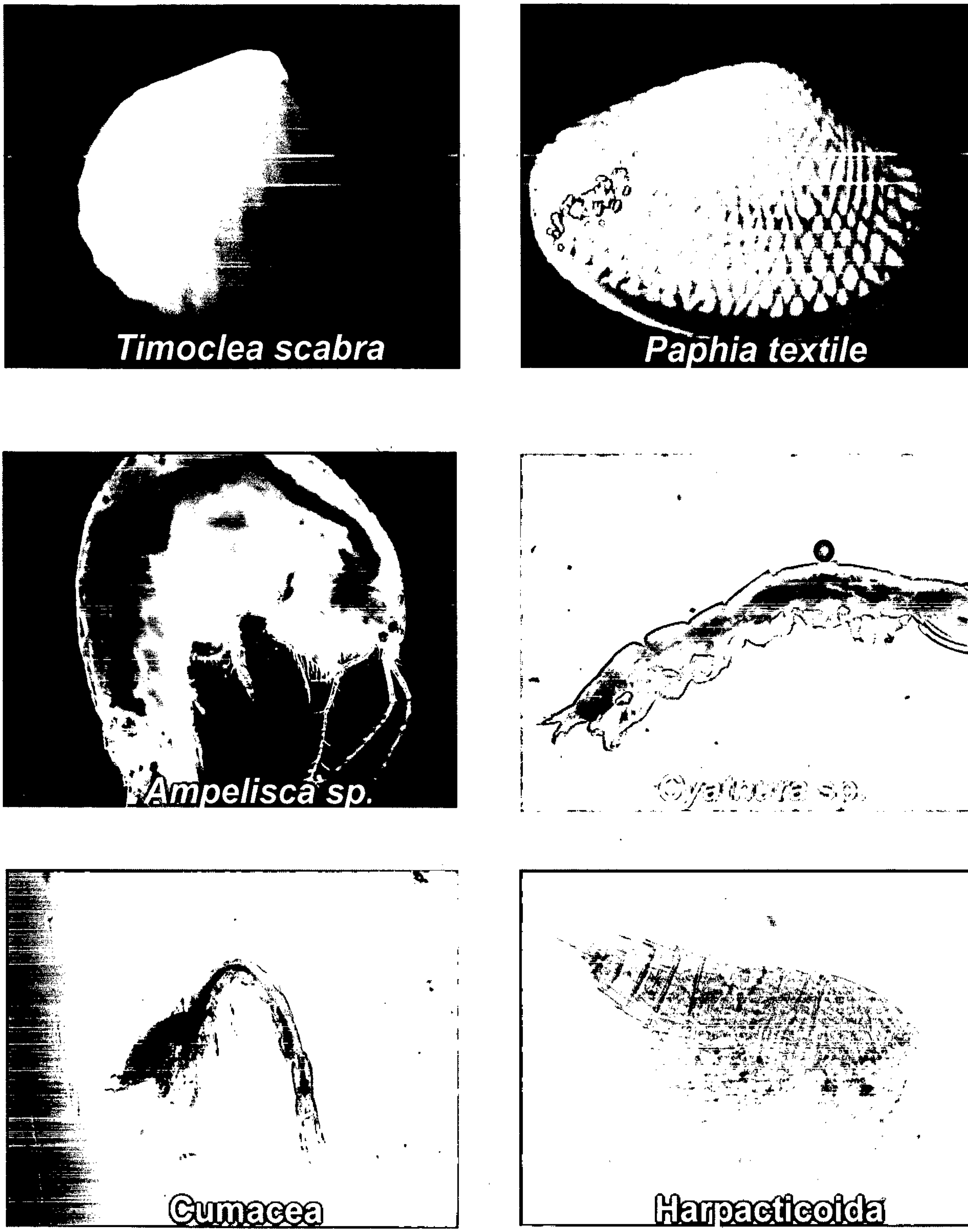


Plate 3.3 Macrofauna from the Mormugao harbour

Chapter 4

Impact of dredging on the macrobenthic community

4.1 Introduction

The successful preservation and promotion of the harbor activities require maintaining the waterways with a regular and fairly intensive dredging and spoiling disposal. Dredging is a human induced disturbance in the marine environment and may be more damaging to the benthic community because of the relative immobility of most benthic organisms. Benthos is the optimal domain for studying the effects of disturbances on the environment, as it has been demonstrated that soft bottom represents 'retentive systems' that are able to record biological processes occurring in the entire system (Danovaro 2000). Most studies on the impact of dredging on marine benthos revealed 30-95% reduction for abundance, biomass and species (Newell et al. 1998), while Desprez (2000) reported complete defaunation of the dredged area. Other effects include enrichment of the surrounding areas due to re-suspension and consequent settlements of fine material (Jones and Candy 1981).

However, impact of dredging could be better interpreted if the physical, chemical and biological characteristics of the ecosystem are studied. Such study is particularly important because it is now widely accepted that ecosystem functioning is dictated by the biodiversity and community structure. The aim of the present study was to evaluate the impact of dredging on the composition and abundance of the macrobenthos from the Mormugoa harbour.

4.2 Materials and Methods

4.2.1 Study Area

Sampling was carried out in the Mormugao harbour (Fig. 4.1). The water depth in the main harbour basin varies from 6-15m. Quantity of the maintenance dredging carried out annually along the navigational channel and harbour basin is about 3.7×10^6 m^3 (Anon, 2004). Dredging is carried out by Trailer suction by the Dredging Corporation of India (DCI). In addition to the regular maintenance dredging, capital dredging was proposed in 2003 for the construction of Bulk Cargo Berths 5A and 6A (0.85×10^6 m^3) to increase the depth from 8m to 13.7m. The dredged materials are disposed at the suitable offshore disposal site (Anon 2004a).

4.2.2 Field sampling and analysis

Sampling was carried out from September 2003-July 2004. Stn D was located in the dredged area. Stn A was considered as adjacent stations as it was within the 500m from the dredged area. Stn C was about 2 km away from the dredged area and therefore considered as control station. Macrofaunal samples were processed as mentioned in Chapter 3. Sediment samples for organic carbon and chlorophyll *a* were obtained separately from the grab samples and processed as mentioned in chapter 2. Data analyses were performed using Primer 6 and Statistica 6.

4.3 Results

4.3.1 Physico-chemical parameters

The important water parameters analysed during the sampling are summarized in Table 4.1. The data did not show significant differences between the stations. The values for suspended solid (SS) were higher in the bottom water at all the three stations. Highest surface and bottom water suspended solid was recorded at stn D. Surface water SS ranged from 0.012-0.045 g l^{-1}. Highest and lowest values were recorded in September and April respectively (Anon 2004a). Bottom water values of SS ranged from 0.012 (November)-0.083 g l^{-1} (December). The surface water SS at stn A ranged from 0.009-0.023 g l^{-1}(0.016 g l^{-1}) and 0.01-0.051 g l^{-1}(0.024 g l^{-1}) in bottom waters. At stn C, values of SS in surface water were highest in February (0.022 g l^{-1}) and lowest of 0.004 in September. In bottom waters, the SS values ranged from 0.014 g l^{-1} (March) - 0.064 g l^{-1} (February).

Sediment granulometry confirmed the heterogeneous nature of the riverbed. Sediments in the dredged and adjacent stations were dominated by silt (85-91%) with notable proportion of clay (5-11%) and showed very little variation in the particle size among the stations. Stn C was dominated by sand (63-95%), silt (3-36%) and clay (0-4%). On an average, granulometric parameters did not show much change during the dredging. An increase in proportion of fine sand was notable with a minor decrease in the coarser fraction at stn D and A.

The values for sediment organic carbon ranged from 0.07 – 3.6 % at stn D (Fig. 4.2a). Higher values were observed in the month of November and lower in May. OC at stn A varied from 0.09-3.31% during September and January respectively. A similar trend was observed at stn C with higher OC during January (2.3%) and lower during September (0.07%). Sediment chl *a* varied from 0.075– 0.65μg g^{-1} in the dredged stations. In the adjacent and control stations, the values ranged from 0.02-0.46 μg g^{-1} and 0.02-0.44 μg g^{-1}, (Fig. 4.2b) respectively. Sediment chl *a* value at stn D and C was highest during September and shows a decline thereafter. At stn A, highest value was in December.

4.3.2 Macrobenthic abundance and biomass

A total of 103 taxa belonging to 10 phyla was recorded from the three stations (Table 4.2). Macrobenthic abundance in the dredged stations ranged from 0-37840 ind m^{-2} (4314±11189 ind m^{-2}; Fig. 4.3). Bivalvia was the dominant group in the dredged area and contributed to 73% of the total faunal abundance whereas polychaetes dominated in the adjacent (69%) and control stations (74%). ANOVA analysis did not show a significant difference between the dredged, adjacent and control stations ($p>0.05$), however the seasonal data showed significant variation in faunal abundance ($p<0.05$).

The bivalve, *C. scabra* dominated the faunal abundance at stn D (73%; Table 4.3) and the values ranged from 0-33599 ind m^{-2}. Polychaetes were next in the order of dominance at stn D (25%). *Chaetozone* sp.1 (0-1922 ind m^{-2}) was the most abundant polychaete followed by *Mediomastus* sp. (0-928 ind m^{-2}), *Cossura* sp. (0-309 ind m^{-2}) and *Prionospio pinnata* (0-419 ind m^{-2}).

Macrofauna at Stn. A was dominated by polychaetes (65%). Nematodes generally are considered as meiobenthic taxa, however, large sized (>1mm total length) specimens, retained on 0.5mm sieve were recorded abundantly at stn A. Their abundance ranged from 0 – 28167 ind m^{-2} and comprised to 15% of the total macrobenthic population of the adjacent station (Table 4.3). Among the large sized nematodes, genus *Eurystomina* and *Pseudocella* (?) were the most dominant. *Polydora coeca* was next in order of dominance (14%) with density ranging from 0- 2264 ind m^{-2} and maximum value being in July. *Mediomastus* sp. contributed to 8% of the total abundance. The abundance of *Mediomastus* sp was high in October (1071 ind m^{-2}). The abundance declined thereafter and *Mediomastus* sp was completely absent during June-July. *Disoma orissae* though reported only in July (1955 ind m^{-2}), it contributed to 7% of the total faunal abundance. *Terebellides stroemi* also contributed significantly (6%) to the faunal abundance and ranged from 0-574 ind m^{-2}.

The abundance of macrofauna at stn C ranged from 11 – 4860 ind m^{-2}. Maximum value was reported in December and minimum in June. The faunal community was dominated by polychaetes contributing to 75% of the total faunal abundance. *Mediomastus* sp. was the most dominant taxa and accounted for 20% of the total abundance. Abundance was maximum in January (2165 ind m^{-2}) and minimum in September (11 ind m^{-2}). *Magelona* sp. was next in order of dominance (12%) and values ranged from 22- 1845 ind m^{-2}. Highest abundance was in December and it was absent from April – July. *Cossura* sp. (7%), *P.pinnata* (5%), *Nephtys polybranchia* (4%), *Axiothella obockensis* (4%) and *C. scabra* were the other dominant species.

The Bray-Curtis and MDS ordination based on macrofaunal abundance at stn C, stn A and within the boundaries of a zone that was actively dredged is represented in Fig. 4.4. The analysis did not show clear demarcation of three sites. The stations showed differences only during the monsoon sampling.

SIMPER analysis was carried to find the species that accounted for the dissimilarity between the three stations (Table 4.4). Stn D showed 91% and 87% dissimilarity with stn A and C, respectively and *T. scabra* was responsible for the differences. Stn A and C also showed variation in their community (86%). *Mediomatus* sp. dominated in the control area and accounted for 11% of the observed dissimilarity.

The macrofaunal biomass showed significant temporal variation but did not vary spatially ($p>0.05$). Highest biomass was recorded in the dredged (27.3 ±75 $g.m^{-2}$) and lowest at control area (6.2 ±11.36 $g.m^{-2}$; Fig. 4.5). Presence of *T. scabra* in very high abundance largely accounted for the high biomass.

A one time capital dredging was carried out during October- April. The faunal abundance showed reducing trend as dredging progressed. Stn D showed 89% reduction after dredging. The area was dredged for the first time for the construction of new berths. The dominant species was *T. scabra* that showed 100% reduction. A similar trend was observed with the other dominant species. Although, the values increased in May (1281 ind m^{-2}), it showed reduction to 88 ind m^{-2} in June with total absence in July. The faunal abundance at stn A and C also showed a decrease, however a gradual one. Stn A showed decline of 14% and stn C showed a 9% reduction during the initial dredging phase. The faunal abundance was low during late pre monsoon and early monsoon. This trend was observed for all the species. *Cossura* sp. and *P. pinnata* were the dominant species during monsoon season. Macrofaunal biomass also showed a drastic decline (96.5%) in the dredged station, mainly due to the significant reduction in the dominant species.

4.3.3 Macrobenthic Diversity

Out of the total 103 macroinvertebrates, maximum numbers of taxa were in the adjacent stations (87) and minimum of 52 taxa were at stn D. Generally, the macrobenthic assemblage, as a whole, was dominated by Polychaeta which comprised of 56.3% of the total identified species. Spionidae, Capitellidae, Paranoidae and Glyceridae were the dominant polychaete families. Molluscs were represented by 15 species (13 bivalves and 5 gastropods) and constituted to 14.5 % of the total identified species. Crustaceans contributed to 18.4% and were represented by Amphipoda (9 taxa), Isopoda (3 taxa), Cumacea (2 taxa), Decapoda (2 taxa) and an unidentified Tanaidacea.

Number of species showed similar trend to that of abundance and biomass with higher counts during post monsoon in all the stations. Values for Shannon-Wiener diversity (*H'*) ranged from 0 – 2.8 at stn D (Fig. 4.6). In stn A , *H'* values ranged from 0.9- 2.3 and 0.69 - 2.0 at stn C. The diversity showed significant variation between stations ($p<0.05$). Evenness did not show significant differences between the stations and varied from 0.29-0.77 in the dredged area. The values showed little variation in the adjacent and control area and ranged from 0.5-0.69 and 0.49- 0.65, respectively. The values for species richness varied significantly between the stations ($p<0.01$) and ranged from 0-2.8 in the dredged station. Values for the adjacent and control stations were 0.5-4.8 and 0.3-4.2, respectively. Impact of dredging on species diversity in general, was similar to that of abundance. Species number and richness was reduced by 27% and 11%, respectively.

4.4 DISCUSSION

4.4. 1 Physico-chemical parameters

Dredging in harbour area to make the channel navigable is one of the major man-made disturbances in the marine environment. In Mormugao harbor, the maintenance dredging is carried out every year after the monsoon. In addition, one time dredging was conducted for new berth construction. The dredging for the former was of smaller scale or involves less sediment being removed, compared to the latter one which was a onetime activity carried out for the construction of Bulk Cargo Berths 5A and 6A and it displaced large amount of sediment. To study the impact of dredging on the macrobenthic community of the harbor, a detailed study was conducted during the onetime dredging, in addition sampling was also conducted during the regular maintenance dredging.

Although the water parameters did not show significant differences between the stations, they demonstrated a strong seasonal influence. Sediment texture in the study area was primarily silty in nature with silt content varying from 58 to 69% at stn D and A respectively. Bottom deposit in the harbour was mainly muddy in the center with sand and silt of riverine origin towards the periphery (Ansari et al. 1994). The dredged area did not show much variation in texture after dredging except for a slight decrease in sand fraction. A non-statistically significant shift towards finer sediment at stn D was possibly caused by reduction of current velocity in the furrows (de Grave and Whitaker 1999). It was in agreement with the study of Van der veer et al, (1985) who suggested that unless dredging results in changed hydrographic conditions, resultant sediment matrix would remain similar to the original one. Nevertheless, large-scale shifts to finer sediment types after dredging have also been documented (Kaplan et al. 1975; Jones 1981), suggesting mixed impact of dredging on the sedimentary parameters. Sediment organic carbon in Mormugoa showed a considerable (50%) increase after dredging activity, especially in the dredged and adjacent stations. Observed increase in OC perhaps was due to the enrichment of the area with refractory carbon mainly due to the re-suspension of displaced material (Sharma 2001). It agreed with our first hypothesis that physical disturbance causes re-suspension of sediments and rapid release of nutrients to the water column (Jones and Candy 1981).

4.4.2 Macrobenthic abundance and biomass

The community was typical of the soft bottom fauna of harbor area as seen in the other stations (chapter 3). The macrofauna at stn D showed the dominance of *T. scabra* which was due the unusually high abundance in November (33599 ind m^{-2}). The fauna during the rest of the period was dominated by polychaetes. The macrofauna abundance and biomass showed a drastic decline of >80% during dredging and *T.scabra* was totally eliminated. The gross reduction in abundance and biomass may be attributed to the removal of organisms and suffocation due to the dredging (Kaplan et al. 1975; Ingole et al. 2004). The suspended solid (SS) was maximum at stn D throughout the study area and showed an increase as dredging progress. Low values of SS were recorded as dredging ceased, indicating the influence of dredging on the SS. However, as compared to the dredge area, minor reduction in SS value was observed in the adjacent and control area. It was unlikely that dredging activity could influence the community of control area, as it was located ≈2 km away from the dredged site. Further, sediment composition of different area also did not vary. Thus, the decrease in faunal abundance at control site therefore could be due to the natural process of recruitment, resources depletion and intra-species competition (Van Dolah et al. 1984).

The macrobenthic abundance/biomass did not show strong significant correlation with any of the environmental parameters. While re-examining the animal-sediment relationship Snelgrove and Butman (1994) concluded that the complexity of soft-sediment communities may defy any simple paradigm with regard to any single factor in controlling their settlement and colonization.

4.4.3 Macrobenthic Diversity

While describing the impact of physical disturbance on the benthic macrofauna, different community variables were considered in this study. However, as shown in Fig. 4.4 many of the variables did not permit an adequate evaluation of the impact of dredging on the macrobenthic assemblage. Species number and richness showed a similar trend to that of macrofaunal abundance and biomass. There was a drastic decrease in the species number at dredged station compared to the other stations where the decrease was gradual. Species evenness did not show significant variation between the stations as the area was dominated by few species (Table 4.3). In fact, the evenness showed an increase as the study progressed (Fig. 4.6) largely due to the decrease in abundance of dominant species. Shannon-Wiener diversity was high at stn A and C. Cluster and MDS showed considerable overlap in the community composition at all the three sites, with little evidence of separation of the community in the dredged stations compared with that of adjacent and controlled stations, as dredging progressed.

Recovery of lost community in the dredged area may take from few days, one month to five or more years depending upon the stocks of potential re-colonizing species and their immigration distance (Bonsdorff 1983; Desprez 2000). Further, the re-colonization rate is supposed to be inversely proportional to the dredging intensity, a low number of furrows being rapidly repopulated by organisms from undisturbed hummocks (McCauley et al. 1977). Consequently, the recovery time of macrobenthic communities after physical disturbance depends on the spatial scale, the hydrodynamic conditions, the sediment grain size and structure of the community affected by the disturbance (Kaiser and Spencer 1996; Pranovi et al. 1998). Recolonization and succession process in the harbour may be controlled by combination of factors (environmental conditions, life history and population processes, and biotic interactions) and vary with spatial scale (Zajac et al. 1998). Natural re-colonization processes may have enhanced immediately after dredging, as evident from the increased abundance in May, especially in the dredged area. Considering the fact that Mormugao harbour is tide dominated, with waters being well mixed, the benthic colonization was probably through water column (larvae and /or adults) (Ingole and Parulekar 1998, Guerra-García and García-Gómez 2003). The hummocks created during dredging activity are highly transitory and may play an important role in maintaining the community structure (de Grave and de Whitaker, 1999). Similarly, while studying the impact of developmental activities on Chilka Lake ecosystem Ingole (2002) observed two fold increase in macrofaunal abundance during the dredging and 08 fold increases during post-dredging, initially due to the exposure of deep-burrowing organism to sediment surface and latter due to the improved food supply and environmental conditions.

Studies conducted elsewhere have suggested that a major structuring force in colonization of infaunal benthic communities was the response of species to resources released from the sediments by periodic disturbances (Santos and Simon 1980; Thistle 1981; Rhoads and Boyer 1982; Peterson 1982). Physical disturbances are common phenomenon in all the harbour area and therefore only those organisms which have capability to withstand disturbing environment, can survive in such habitat. This was evident in the present study where opportunistic polychaetes such as *P. pinnata*, *Mediomastus* sp., *Cossura* sp., *Tharyx* sp. were the fast colonizers, while crustaceans like amphipods and molluscs were rather slower in re-colonization (McCauley et al. 1977). In the present study, it was difficult to differentiate between the dredging and natural seasonal changes in the community. The cessation of the dredging was followed by the monsoon season. In the tropical estuaries, increased salinity during pre monsoon triggers the reproduction in most of the benthic fauna (Bemvenuti 1987; 1997; Ingole and Parulekar 1998).

The observed change could have been due to the normal seasonal fluctuations, because comparable decrease was also observed in the adjacent and control areas. In fact, it was difficult to study the actual impact and the time taken for the recovery of the fauna as monsoon followed the dredging activity. It is believed that the new recruit from the surrounding areas may facilitate faster recolonization of the dredged site. Thus, it can be concluded that a one time dredging will have minimum impact on the bottom fauna unless the dredging has caused significant variation in the sediment texture. The natural disturbance in the area represented confounding influences on impact of dredging on the macrobenthic community of the Mormugao harbour.

The impact of dredging on the macrofaunal community may occur only if dredging is carried out frequently as seen in the channel station (stn 5; Chapter 3). Therefore, the comparison of the total fauna community in the area indicated only short-term and localized effects from dredging and agrees well with other similar studies (Stickney and Perlmutter 1975; Van Dolah et al. 1984; de Grave and Whitaker 1999; Guerra-García et al. 2003). The low impact of dredging on the macrobenthic community of the harbour area was probably due to strong tidal currents which rapidly dispersed the dredged mud released away from the area. Further, the benthic communities, in the continuously disturbed area may have ability to recover rapidly.

4.5 CONCLUSION

Mormugoa is one of the leading iron ore exporting ports of the world. Maintenance dredging is conducted regularly both in the harbour basin and channel for safe navigation of vessels. In addition, one time capital dredging was conducted for the construction of new berth. The study highlights the difficulties in studying the impact of disturbance in areas with varying environmental characteristics.

Table 4.1
Variation of in water parameters (range) in the study area*

	Stn D (Dredged)	Stn A (Adjacent)	Stn C (Control)
Suspended Solid (S) (g l^{-1})	0.012-0.045	0.009-0.023	0.004-0.022
Suspended Solid (B) (g l^{-1})	0.012-0.083	0.01-0.051	0.014-0.064
S Chl *a* (μg l^{-1})	0.45-5.12	0.7-9.8	0.45-18.47
B Chl *a* (μg l^{-1})	0.45-3.41	0.51-7.67	0.57-4.8
S Phaeo (μ g l^{-1})	0.06-1.14	0.14-4.4	0.17-4.5
B Phaeo (μg l^{-1})	0.11-1.14	0.2-3.2	0.17-1.9
S DO (mg l^{-1})	4.8-6.2	6.0-6.7	5.3-6.2
B DO (mg l^{-1})	1.8-5.7	4.0-5.7	2.9-5.7
S BOD (mg l^{-1})	0.2-1.34	0.74-1.5	0.56-1.6
B BOD (mg l^{-1})	0.4-1.4	0.25-1.3	0.4-1.6

*Source: Anon 2004a

Table 4.2
Macrobenthic community in the area (+: Present; -: Absent)

Taxa	Stn D	Stn A	Stn C
Obelia colony #1	+	+	+
Obelia colony #2	-	+	+
Hydroid	+	+	+
Nematoda	+	+	+
Nemertenia	+	+	+
POLYCHAETA			
Phyllodoce malmgreni	+	+	+
Phyllodoce madeirensis	+	-	+
Phyllodoce sp.	-	+	+
Eteone sp.	-	+	-
Syllis krohnii	-	+	-
Syllis sp.	-	+	+
Exogene sp.	-	+	-
Harmothoe sp.	-	+	-
Ancistrasyllis constricta	+	+	+
Ancistrasyllis groelandica	+	-	-
Nepthys polybranchia	+	+	+
Nereis sp.	+	+	+
Glycera alba	+	+	+
Glycera longipinns	+	+	+
Glycinde oligodon	-	-	+
Goniadides sp.	+	+	+
Goniada hexadentes	+	-	+
Goniada sp.	-	+	-
Pisione oesterdii	-	+	-
Tharyx spp.	+	+	+
Chaetozone sp. 1	+	+	+
Chaetozone sp. 2	+	+	+
Mediomastus sp.	+	+	+
Notomastus sp.	+	-	+
Capitellidae	+	+	+
Euclymene insecta	+	+	-
Axiothella obockensis	+	+	+
Prionospio pinnata	+	+	+
P. krusadensis	-	-	+
Polydora sp.	+	+	-
Polydora ciliate	-	+	+
P. coeca	+	+	+
P. antennata	+	+	+
Pseudopolydora kempi	+	+	+
Minuspio cirrifera	+	+	+
Magelona sp.	+	+	+
Poecilochaetus serpens	-	+	+
Phyllochaetopterus sp.	-	-	+
Disoma orissae	-	+	-
Dorvillea manadapmae	+	+	+

Contd.........

Table 4.2 Contd....			
Taxa	**Stn. D**	**Stn. A**	**Stn. C**
Lumbriconereis laterelii	+	+	+
Lumbriconereis sp.	-	+	-
Eunice indica	-	+	+
Dioptra clapaderi	+	+	+
Onuphis eremita	+	+	+
Onuphis dibranchiata	-	+	+
Terebellides stroemi	+	+	+
Sabellaria cementaria	-	+	+
Jasmineria sp.	-	+	+
Sternapsis scutata	+	-	+
Scoloplos spp.	+	+	+
Aricidea catherina	+	+	+
Paradoneis armata	-	+	-
Levinsenia sp.	+	+	+
Cossura sp.	+	+	+
Armandia lanceolata	+	+	-
Unidentified Polychaeta	-	+	-
Oligocheata	+	+	+
Sipuncula	-	-	+
Phoronida	-	+	-
Bivalvia			
Nuculana sp.	-	-	+
Modiolous sp.	-	+	+
Cardaita bicolor	-	+	+
Venerupis sp.	-	+	-
Sunetta sp.	-	+	+
Paphia textile	+	+	-
Sunetta sp.	-	+	-
Pitar erycina	-	+	-
Timoclea scabra	+	+	+
Venus sp.	-	+	+
Gafrarium sp.	-	+	+
Mactra sp.	-	+	-
Tellina sp.	-	+	+
GASTROPODA			
Marginella	-	+	-
Olivia sp.	-	+	+
AMPHIPODA			
Ampelisca sp.	-	+	+
Cheirocratus sp.	-	+	-
Monoculodes sp.	-	-	+
Westwoodilla sp.	+	-	-
Pallasia sp.	-	-	+
Photis spp.	+	+	+
Gammaropsis sp.	-	-	+
Corophium sp.	-	+	+
Podocerus sp.	-	+	-

Contd.........

Table 4.2 Contd....			
Taxa	**Stn. D**	**Stn. A**	**Stn. C**
Tanidacea	+	+	+
CUMACEA			
Pseudocyclaspis sp.	-	+	+
Unidentfied	+	+	+
ISOPDA			
Cyathura sp.	+	+	+
Accanthura	-	+	-
Valvifera	+	+	+
Unidentifed Isopoda	-	+	-
Ostracoda	-	+	+
DECAPODA			
Thalasinid shrimp	-	+	-
Carridean shrimp	-	+	-
Ophiuridae	+	+	+
Insect larvae	-	-	-
Fish	+	-	+

Tables 4.3
Percent composition of dominant macrobenthic species in the study area

	Stn D	**Stn A**	**Stn C**
Nematoda	0.04	16	2.2
Chaetozone sp. 1	4	1.5	1
Mediomastus sp.	4.5	7.8	19
Prionospia pinnata	2.5	2.2	4.5
Polydora coeca	1.3	14	5.8
Magelona sp.	1	1.5	11
Disoma orissae	0	6.8	0
Terebellide stroemi	0.4	6	1.7
Jasmineira sp.	0	3.2	0.8
Scoloplos spp.	0.4	3.3	2
Cossura sp.	2.2	3	6.6
Modiolous sp.	0	3.9	0.5
T. scabra	72	1.7	3
Nepthys polybranchia	0.5	3.6	3.8

Table 4.4
SIMPER analysis showing the species that contributed to the differences among the three stati
Av. Abund: average abundance; Av. Diss: Average dissimilarity; Contrib: Contribution

Av dissimilarity 91 %	**Stn D**	**Stn A**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
T. scabra	3138.79	44.18	11.65	0.46	12.75	12.75
Nematoda	2.01	399.63	7.86	0.5	8.6	21.35
Cossura sp.	98.4	69.28	5.9	0.84	6.46	27.81
Mediomastus sp.	196.8	183.75	5.9	1.03	6.45	34.27
N. polybranchia	22.09	92.38	5.61	0.55	6.14	40.41
P. coeca	56.23	298.22	5.32	0.42	5.83	46.24
P. pinnata	108.44	59.24	3.98	0.65	4.35	50.59
Chaetozone sp. 1	176.72	41.17	3.7	0.38	4.05	54.64
T. stromiae	20.08	159.65	3.54	0.66	3.87	58.5
D. orissae	0	177.72	3.28	0.3	3.59	62.09
Scoloplos sp.	18.07	78.32	2.72	0.83	2.98	65.07
Paphia textile	28.11	22.09	2.35	0.38	2.58	67.65

Av dissimilarity 88%	**Stn D**	**Stn C**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
T. scabra	3138.79	64.26	12.43	0.49	14.13	14.13
Mediomastus sp.	196.8	413.69	11.53	0.92	13.11	27.24
Cossura sp.	98.4	137.56	8.14	0.8	9.25	36.49
Magelona sp.	40.16	245	7.72	0.7	8.77	45.26
P. pinnata	108.44	94.38	4.76	0.81	5.41	50.67
Fish	2	162.66	3.71	0.31	4.22	54.89
Chaetozone sp. 1	176.72	19.08	3.64	0.38	4.14	59.03
N. polybranchia	22.09	81.33	3.55	0.75	4.04	63.07
Nematoda	2.01	42.17	2.77	0.34	3.14	66.21
Tharyx spp.	26.11	16.07	2.54	0.28	2.89	69.1

Av dissimilarity 86%	**Stn A**	**Stn C**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Mediomastus sp.	183.75	413.69	9.54	0.87	11.07	11.07
Nematoda	399.63	42.17	8.26	0.63	9.58	20.64
Magelona sp.	39.16	245	6.27	0.65	7.28	27.92
Polydora coeca	298.22	109.45	5.98	0.5	6.94	34.86
Cossura sp.	69.28	137.56	5.21	0.7	6.05	40.91
N. polybranchea	92.38	81.33	4.06	0.6	4.7	45.61
T. stroemi	159.65	36.15	3.44	0.77	3.99	49.6
Fish	0	162.66	3.13	0.3	3.64	53.24
D. orissae	177.72	0	3.05	0.3	3.53	56.77
P. pinnata	59.24	94.38	2.71	0.87	3.14	59.92

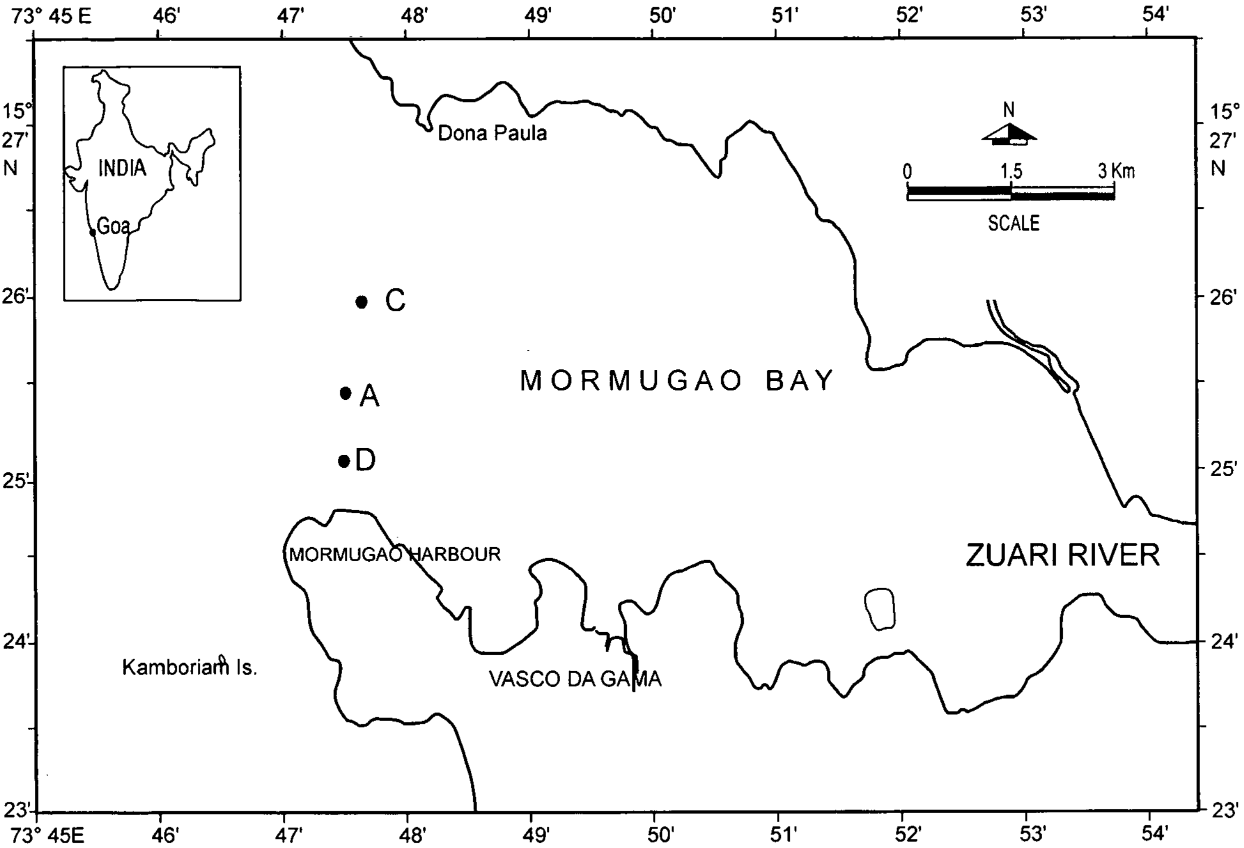


Fig 4.1 Location of the Dredged (stn D) , Adjacent (stn A) and Control (stn C) in the Mormugao harbour

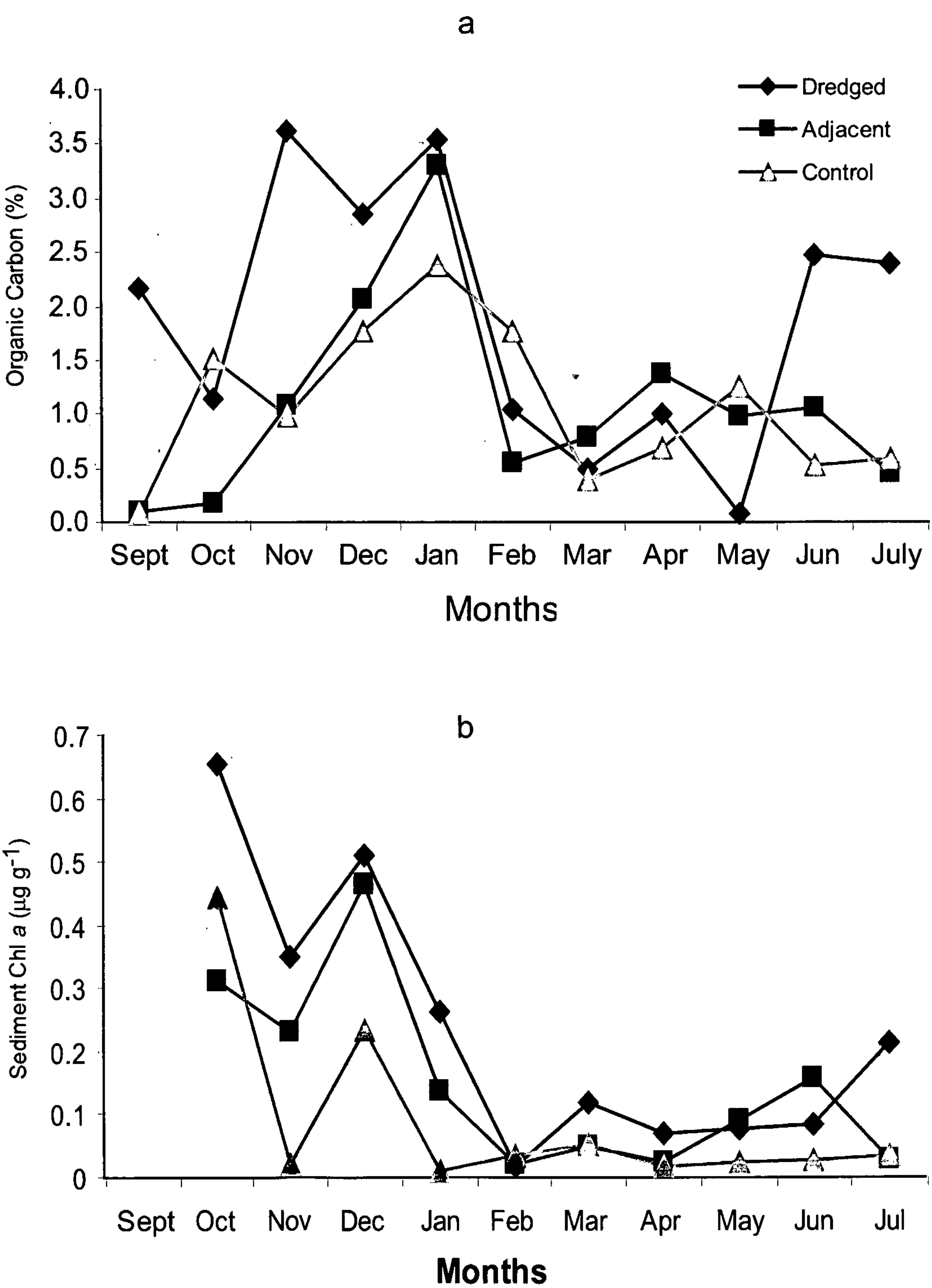


Fig. 4.2: Monthly variation in organic carbon(a) and sediment Chl a (b) at the three stations

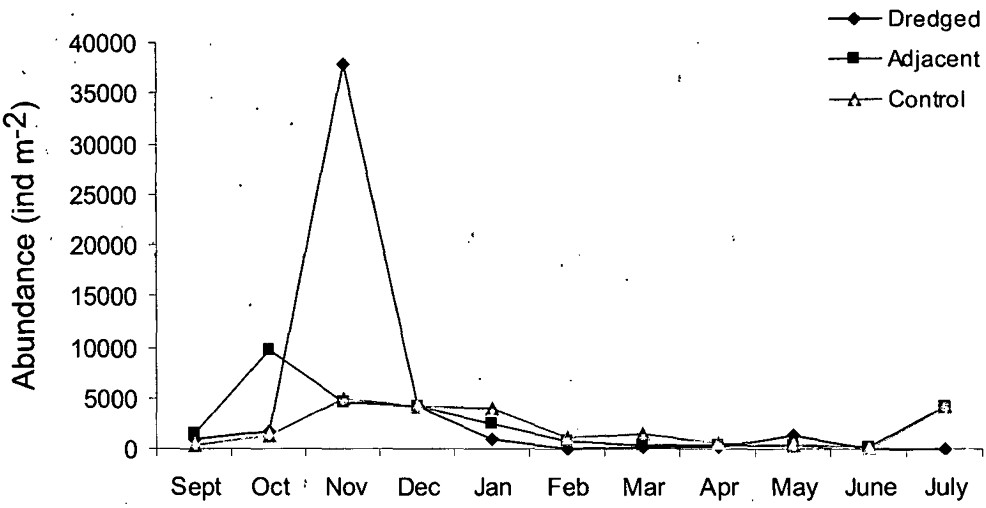


Figure 4.3 Monthly variation of macrofaunal abundance at the three stations

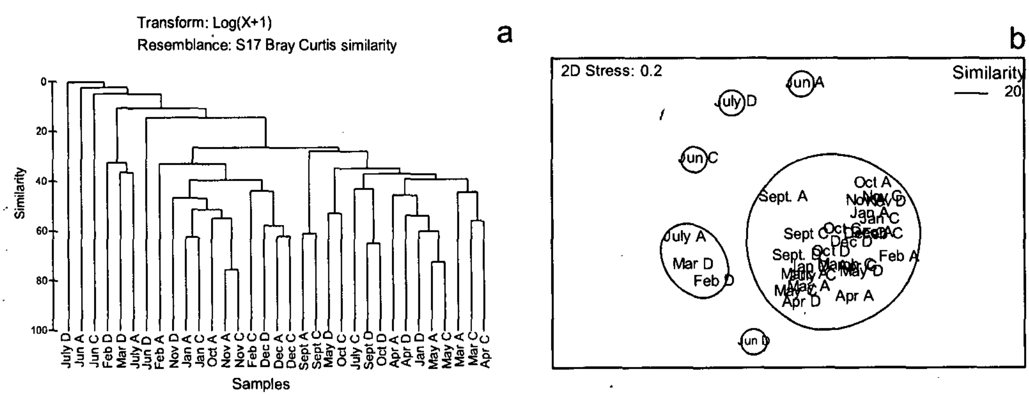


Fig 4.4 Bray-Curtis cluster (a) and MDS (b) based on macrofaunal abundance at the three stations

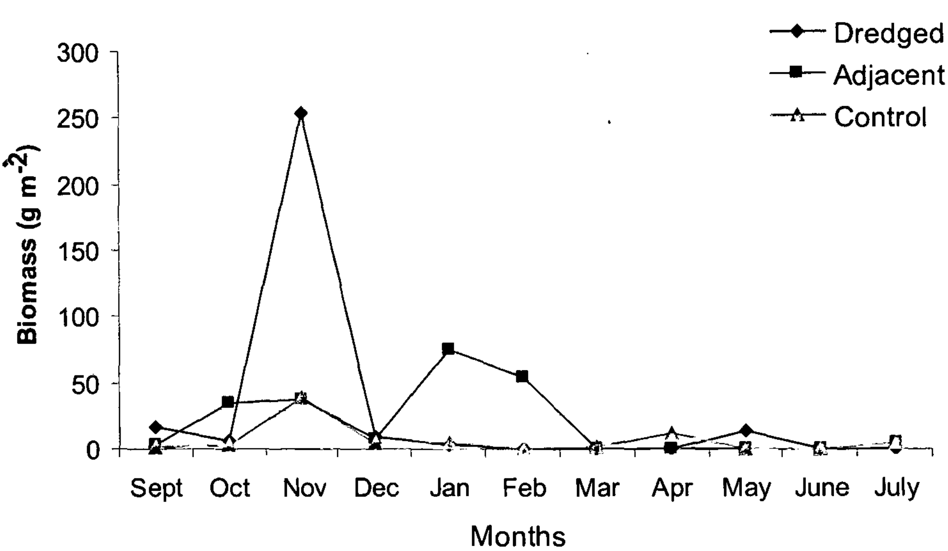


Fig 4.5 Monthly variation of macrofaunal biomass at the three stations

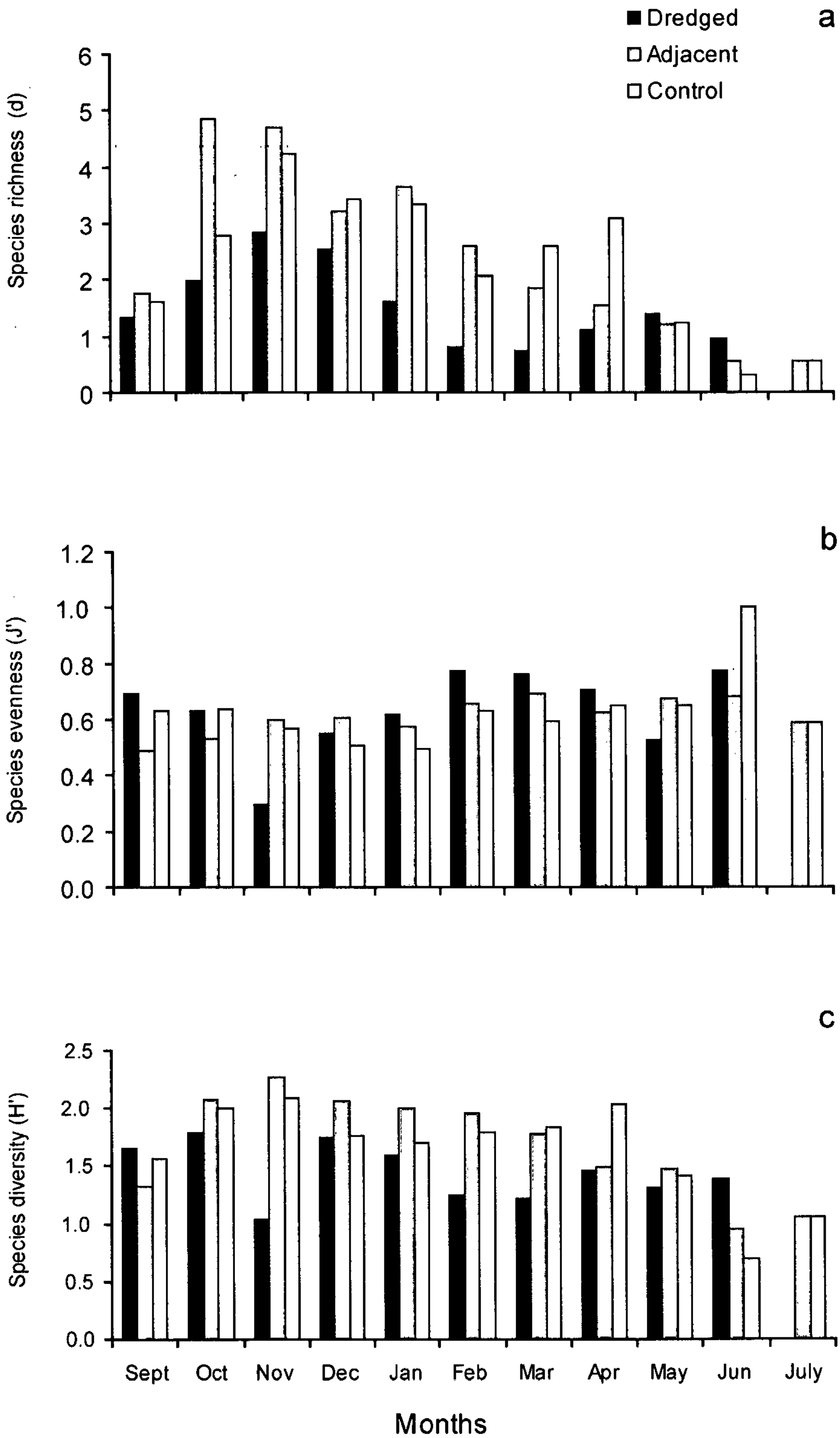


Fig. 4.6 Monthly variation in macrofaunal species richness (a), species evenness (b) and species diversity (d)

Chapter 5

Comparative study of macrobenthic community in three harbours along the west coast of India

5.1 Introduction

Harbours are the lifeline of a country's economy as bulk of the trade takes place through them. However, from the environmental point of view they are the most altered coastal habitats and cause considerable pollution of water, air and land. Further, several other activities like fisheries, industries and tourism occurs in and around the area that may have an impact on the environment. The harbours are characterised by reduced dissolved oxygen level and higher concentration of pollutants in water and sediment (Danulat et al. 2002; Rivero et al. 2005).

In general, levels of pollution along the Indian coast are increasing and the west coast perhaps, is more polluted compared to the east coast (Sengupta et al. 1989; Zingde 2002). This may be because most of the harbours are located along the west coast resulting in higher movement of transport vessels. In fact, two of the major oil routes of the world pass through the Indian water and 70% of the world's oil is transported through this route (Anon 2003). In addition, over 53,684 mechanised trawlers and about 2, 25862 traditional fishing vehicles operate along the coastal waters of India (Somvanshi 2003). Further, the west coast of India is recognized as biodiversity hotspot (Ingole 2004; Venkatraman and Wafar 2005) and contributes to >70% of the countries marine capture fishery.

Mormugao is a major commercial port whereas; Karwar and Ratnagiri are minor ports along the central west coast of India. However, in recent years the commercial activities are on an increase in all the three harbours. In view of this, the respective state governments have considered the expansion. Further, the coastal waters between Ratnagiri and Karwar are recognized as active fishing zone (Madhupratap et al. 2001; Ingole et al. 2002). Due to their strategic location along the central west coast of India, the importance of all the three harbours is considered to further increase in years to come. Thus, the coastal areas along the central west coast of India are a suitable ecosystem to observe the impact of harbour activities by studying the macrobenthic community.

Although studies have been performed along Mormugao, Karwar and Ratnagiri coast, very few biological studies corresponding specifically to the macrobenthic community of the harbour have been carried out. Thus, the present study aims to contribute to the knowledge of the macrobenthos and its potential use as diagnostic tool for assessing the environmental health.

5.2 Materials and Methods

5.2.1 Study area

Field sampling was conducted at Mormugao, Karwar and Ratnagiri (Fig.5.1). The Mormugao harbour is situated near the historic city of Vasco-da-Gama (15°27'48" N; 73°38'64"E) along the Goa coast. Mormugao port, with a fine natural harbour is one of the oldest major ports on the west coast of India. The port accounts for about 39% of India's iron ore exported and ranks within the first ten leading iron ore exporting ports of the world. During the financial year 2003-2004, the port handled 8% of the total traffic handled by all the twelve major port of India. Ratnagiri harbour is situated (17°00'38" N and 73°15'34"E) in the Mirya Bay along the Maharashtra coast. Karwar port is situated in north Karnataka (14° 50' 36" N and 73° 54' 55" E) in the mouth of Kali estuary. Karwar is one of the best natural all weather harbour. It has a 355 m long quay for accommodating simultaneous berthing of two ocean-going ships. The harbour is used for loading and unloading of all types of commodities including petroleum products. The water depth in the study area varies from 5-40 m. The sediment in the inner harbour was generally dominated by silt and clay whereas; outer harbour has higher content of fine sand.

5.2.3 Sample Collection

Sediment samples were collected on board *CRV Sagar Sukti* (SASU-105) in January 2006 using van Veen grab (0.11 m^2). Sub sampling was done with a quadrant (225 cm^2). Two stations were sampled in each harbour. Five grabs were collected from each station at Ratnagiri (Rat 1 and Rat 2) and Karwar (Kar 1 and Kar 2) and triplicate samples from Goa (Goa 1 and Goa 2). Reference station was not taken as the sediment outside the harbour was dominated by sand in all the three harbours. All the samples were sieved on board through a 0.5mm mesh, and the materials retained were preserved in 5% buffered formalin Rose-bengal solution. In the laboratory, macrofauna was sorted, counted and identified to the lowest possible taxonomic level. Group-wise biomass was measured by wet weight method.

At each station, sediment sample was also taken with acrylic core (Ø 4.5 cm) for the analysis of sediment chlorophyll, phaeopigment and organic carbon. Chlorophyll *a* (Chl *a*) and phaeopigment were analysed by acetone extraction method (Holm-Hansen, 1978) and organic carbon was estimated with CO_2 Coulometer after acidification of sediment to remove the inorganic carbon.

5.2.4 Data Analysis

Faunal data was processed using univariate and multivariate methods using PRIMER E as mentioned in chapter 3. Geometric class, ABC curves and the benthic opportunistic polychaete:amphipod index were used to determine the environmental status of the study area (Chapter 3).

5.3 Results and Discussions

The sediment chl *a* values ranged from 0.18- 0.35 $\mu g\ g^{-1}$ with highest values recorded in Mormugao and lowest at Ratnagiri harbour. Sediment organic carbon ranged from 1.4-3.5% with highest values in Goa. Since all the three harbours are located in close proximity of highly populated towns, the organic loading in the area may be mainly from the inflow of domestic waste and fishing activities (Ansari et al. 1994). Moreover, the harbours are located near the mouth region of the estuary, which brings significant amount of organic material from the upper reaches and deposit in the estuary. River flow is considered to be another major source of organic load in harbours (Webber and Kelly 2003).

The macrofaunal community in the present study was comprised of 55 taxa belonging to 6 phyla (Table 5.1). Although, the ecological setting as well as water depth in all the three harbour were similar (varying from 5-30m) macrofauna showed significant variation in composition and abundance. The macrobenthic abundance ranged from 1214 -15407 ind m^{-2} (6135±5045.8; Fig 5.2). Stations in Ratnagiri recorded the highest abundance and lowest values were in Goa. The macrobenthic abundance did not show significant variation within the harbour ($p>0.05$) but differed significantly between the harbours ($p<0.001$). Biomass (wet wt.) also showed greater variability between the stations and ranged from 0.14 (Goa) to 145.77 g m^{-2} (Karwar). The higher biomass was largely due to the occurrence of bigger sized echiurids, accounting to 85 % of the macrofaunal biomass at Karwar. Biomass value shows significant variation within stations ($p<0.03$), however biomass did not show significant variation between the harbours ($p>0.05$).

Polychaetes were numerically dominant accounting for 96% of the total macrofauna. Dominance of polychaete worms was as expected for harbour area and compares well with other harbour studies (Raman 1995; Belan 2003; Guerra-García and García-Gómez 2004; Rivero et al. 2005). The abundance data was subjected to Bray-Curtis cluster analysis and detected three groups (Fig. 5.3a). Group I consisted of Ratnagiri stations with 66.36% similarity. Goa 1 and Goa 2 (Group II) clustered at 69.73% and third group comprised of Karwar stations (80.24%). MDS ordination confirmed the results of cluster, and detected the same three groups (Fig. 5.3b). The community data was subjected to SIMPER analysis to find the species, which contributed to the similarity within each group. Accordingly, Ratnagiri was dominated by *Mediomastus* sp. (42.35%), *Prionospio pinnata* (24.76%), *Cossura* sp.; Group II (Goa)- *P.pinnata* (30.88%), *Eunice* sp. (17.65), *Aricidea* sp. (8.82%) ; Group III (Karwar) - *P. pinnata* (53.6%), *Notomastus* sp. (21.58), *Mediomastus* sp. (12 %). The species, which resulted in the dissimilarity in the three harbours, are listed in Table 5.2.

The species composition showed that, the macrobenthic community was represented by fewer species which contributed to >60% of the total abundance (Table 5.3). *P.pinnata*, *Mediomastus* sp., *Notomastus* sp. of the family Spionidae and Capitellidae dominated. Species belonging to the above families are largely opportunistic and proliferate in sediments with high organic enrichment (Pearson and Rosenberg 1978; Glémarec and Hilly 1981). Further, Spionidae and Capitellidae contributed to 20% of the total polychaete species (Table 5.1). High organic content in sediment can promote the abundance of some tolerant species and reduce sensitive species (Pearson and Rosenberg 1978). *P.pinnata* was the most dominant species at Goa and Karwar, which also showed the highest organic carbon values. *P. pinnata* is a cosmopolitan species occurring in organically rich sediment and in areas subjected to continuous disturbance (Pearson and Rosenberg 1978). In Ratnagiri, *Mediomastus* sp. contributed to 36% of the macrofaunal abundance. *Mediomastus* sp. is reported to dominate in areas of moderate disturbance and high energy environment (Rivero et al. 2005). In fact, species belonging to the genus *Mediomastus* sp. flourish in habitat with moderate amount of organic matter with total absence in area of high organic pollution (Pearson and Rosenberg, 1978).

The dominance of few species was further confirmed from the geometric abundance curve (Fig. 5.4). In the geometric abundance curve, the number of species represented by a single individual are in class 1, 2-3 individuals in class 2, 4-7 (class 3), 8-15 (class 4) and so on. In unpolluted situation, the community is represented by rare species resulting in a smooth curve with its mode to the left. In polluted condition, the community is represented by few rare species and abundance of few species, so that higher geometric abundance classes are more strongly represented and the curve become irregular. In the present study, the geometric abundance curves are very irregular and extend from class 2 - 13 for Ratnagiri (Fig. 5.4 a) and class 2-10 in Mormugao (Fig. 5.4 b) and to class 2-12 in Karwar (Fig. 5.4c). Therefore, it can be concluded that the area under investigation was dominated by higher abundance of few species, perhaps resulting from stress conditions due to anthropogenic activities.

Most invertebrate species observed during this investigation were small in size. The possible explanation for the presence of small-sized polychaetes is that the area is frequently disturbed by natural and anthropogenic factors. All the three harbour are located towards the estuarine mouth, an area in the estuary with the strongest hydrodynamics. Further, to maintain required water depth in the harbours, the area is regularly dredged. This may have resulted in the dominance of small, opportunistic, tube-dwelling polychaetes, which are the first faunal components to colonize in disturbed areas (Rhoads and Boyer 1982). A similar association of small sized polychaetes was observed in the northern shallow shelf of Chile and Peru affected by sewage discharge (Carrasco 1997).

Crustaceans were the second dominant group and the community was represented by a total of 16 species (Table 5.1). The most dominant was the amphipod *Ampelisca* sp., with highest abundance recorded in Mormugao harbour (755 ind m^{-2}). In fact, *Ampelisca* sp is known to be dominant in muddy sediments and are well adapted to stress environment (Lowe and Thompson 1997).

The number of species ranged from 21 species (Goa 2) to 36 species at Rat 2. Species richness (d) was also highest at Rat 1 (1.7) and lowest at Goa 2 (1.1; Fig 5.5). Species diversity (H') was lowest at Kar 1 and Rat 2 (1.4.) and highest at Rat 1 (2.1). Generally, the estuarine communities are subjected to greater natural stress than those in non-polluted coastal waters and are expected to show lower macrobenthic diversity index. Wilhm and Dorris (1966) stated that values <1.0 for diversity index (*H'*) in estuarine waters was common when heavy pollution occurred; values between 1.0 and 3.0 indicated moderate pollution; and values exceeding 3.0 characterized non-polluted water. Diversity value in the study area ranged from 1.6 to 2.4. Thus, clearly indicates that the harbours are polluted and the macrobenthic community is under stress due to natural and/ or anthropogenic factors. Evenness (*J*) was higher in Goa (0.8) and lower at Rat 2 (0.58). The lower *J* values obtained at Rat 2 were due to the dominance of *Mediomastus* sp., *P. pinnata*, *Prionospio* sp. and *Cossura* sp. together contributed to 91% of the total macrofaunal abundance. Two-way ANOVA showed significant differences in species number and evenness ($p<0.05$) between the harbours. Within the site, significant differences in species diversity ($p<0.05$) were however observed only at Ratnagiri.

Various biotic indices have been formulated to study the pollution status of the marine environment. The opportunistic polychaete/amphipod ratio (P: A) based on ecological groups was used in the present study (Dauvin and Ruellet 2007). The P: A ratio ranged from 0.22 in Mormugao to 0.27 in Karwar. P: A values 0 indicate unpolluted condition and 0.3 indicates a grossly polluted condition. The abundance/ biomass comparison (ABC) approach is recommended by Warwick (1986) who stated that, the ABC is suitably an abbreviated descriptor of the state of marine pollution. In certain cases the ABC curve can give wrong picture and can be overcome by the use of partial dominance curve (Warwick and Clarke 1994). In Goa, the abundance curve crossed the biomass curve at several points which was mainly due to the dominance of small sized polychaete species having high abundance but low biomass (Fig. 5.6 a). The ABC curve showed partial dominance of abundance over biomass at Ratnagiri (Fig. 5.6b) and at Karwar the biomass curve dominated over the abundnace curve (Fig.5.6 c) with crossing at two points. The dominance of biomass curve at Karwar and Ratnagiri was due to the dominance of echiurans that accounted to > 80% of the total biomass. The ABC curve is based on the concept that polluted areas are dominated by small-sized species with low biomass. However, dominance of large sized bioindicators, as in the present study can give a “wrong” picture of the pollution status of an area. Echiurans are deposit feeders inhabiting fine-grained, organically rich sediment. Stull et al. (1986) observed that the echiuran worm, *Listriolobus pelodes* reduced the negative effects of wastewater discharge like reducing the pore water hydrogen sulphide and showed high diversity in the coastal shelf region of Palos Verdes, S. California. This was evident from decrease in diversity and increase in opportunistic species of polychaete (*Capitella capitella*) after the decline of the echiuran worm (Stull et al. 1986).

The use of biotic indices have often been criticised as many of the indices have given wrong interpretation in areas, which are naturally stressed. Therefore, the combinations of indices have been suggested. In the present study, various univariate and multivariate indices were used to detect the degree of pollution. Though all the indices showed a polluted condition the degree of pollution differed. Species richness, abundance of stress tolerant/sensitive species and trophic function and composition were the most successful measurement in differentiating the diversity grade of pollution leading us to think that increase or decrease in the number of tolerant/sensitive species is one of the best disturbance indicator and therefore, essential when it comes to differentiate ecological states. Vincent et al (2002) observed that the methods combining composition, abundance and sensitivity might be the most promising. Species richness was highest at Ratngairi and was dominated by deposit feeding *Mediomastus* sp. The area also showed the lowest organic carbon content (1.4%). On the other hand, lowest species richness and highest organic carbon were seen at Goa (3.5%) and Karwar (2.8%). Moreover, opportunistic *P.pinnata* dominated the area. The high pollution at Goa and Karwar harbour are expected since the shipping activities are higher compared to Ratnagiri harbour.

The benthic communities are strongly linked to higher trophic levels; therefore any alteration of their trophic structure potentially affects the fishery production of an area. Fisheries in estuarine regions depend more on taxa available at the sediment surface, such as amphipods, mysids, and surface deposit feeders (SDF) polychaetes, than on subsurface deposit feeders (SSDF) (Hines et al. 1990; Franz and Tanacredi, 1992). Demersal fish constitutes the major portion of the commercial fish landing (particularly the prawns) and any change or alteration in benthic standing stocks will reflect directly in the demersal fish production. Preliminary results of the recent coastal surveys also suggest increasing level of pollution at Ratnagiri, Goa and Karwar (Anon 1996; Nanajkar and Ingole 2007). This along with the increased fishing efforts, over-fishing, may be the main cause for decline in the fishery production of the area (Ansari et al. 2006). Although, macrofaunal abundance was relatively higher at Ratnagiri compared to Goa and Karwar, the fauna was largely comprised of the small-sized, opportunistic annelid species that did not contribute significantly to the benthic biomass.

5.4 Conclusion

Continuous assessments of areas under stress, such as harbour, are therefore needed to determine the temporal changes in the community. The long-term monitoring can be time-consuming and expensive. Therefore, the concept of bioindicator should be attempted to use their presence in an area to characterise a certain degree of community change or pollution effects. This approach has been widely applied to benthic monitoring studies and was successfully used in the present study to determine the impact of harbour activities on the marine environment along the central west coast of India.

Table 5.1
Macrobenthic species list of the study area (+ present; - absent)

Stations	Rat 1	Rat 2	Goa1	Goa2	Kar 1	Kar 2
Echiurida	+	+	-	-	+	+
Sipuncula	-	+	+	-	-	-
Polychaeta						
Family Phyllodocidae						
Phyllodoce sp.	-	+	+	+	-	-
Eteone sp.	-	+	-	-	-	+
Family Aphroditidae						
Sthenelais sp.	-	-	-	+	-	-
Family Syllidae						
Syllis comuta	-	-	-	+	-	-
Family Pilargiidae						
Ancistrosyllis sp.	+	+	+	-	-	+
Cabira sp.	+	+	-	-	+	+
Pilargidae	-	-	-	-	-	+
Family Nephtyidae						
Nephthys sp.	+	+	+	+	+	-
Family Nereidae						
Nereis sp.	+	+	+	-	-	+
Family Glyceridae						
Glycera alba	+	+	+	-	+	+
Glycera sp.	+	-	-	-	+	+
Family Goniadidae						
Glycinde sp.	-	+	-	-	+	-
Family Cirratulidae						
Tharyx sp.	+	+	+	+	-	-
Family Spionidae						
Prionospio krusadensis	+	-	-	-	-	-
Prionospio pinnata	+	+	+	+	+	+
Prionospio sp.	+	+	+	+	+	+
Family Magelonidae						
Magelona sp.	-	+	-	-	-	-
Family Capitellidae						
Mediomastus sp.	+	+	+	+	+	+
Notomastus sp.	-	+	+	+	+	+
Capitellidae	-	-	-	-	-	+
Family Dorvilleidae						
Dorvillea sp.	+	-	+	+	-	-

Contd............

Table 5.1 Contd...

Stations	Rat 1	Rat 2	Goa1	Goa2	Kar 1	Kar 2
Family Lumbrineridae						
Lumbriconereis latereilli	+	+	+	+	+	+
Family Eunicidae						
Eunice sp.	+	-	+	+	-	-
Family Onuphidae						
Onuphis sp.	+	-	+	+	-	-
Family Sternaspidae						
Sternaspis scutata	+	-	-	+	-	-
Family Terebellidae						
Terebella sp	+	-	+	+	-	-
Family Sabellidae						
Jasmineira sp.	+	+	+	+	-	-
Hypsicomus sp.	-	+	-	-	-	-
Family Serpulidae						
Hydroides sp	-	+	+	+	+	+
Family Cossuridae						
Cossura sp.	+	+	+	+	+	+
Family Paraonidae						
Aricidea sp.	+	+	+	+	+	+
Levinsenia sp.	+	-	+	+	+	+
Amphipoda						
Family Ampeliscidae						
Ampelisca sp.	+	+	+	+	+	+
Family Hyalidae						
Hyale sp.	+	-	-	-	-	-
Family Haustoriidae						
Urothoe sp.	-	+	-	-	-	-
Family Oedicerotidae						
Synchelidium sp.	+	+	-	-	-	-
Family Liljeborgiidae						
Liljeborgia sp.1	+	+	-	-	+	-
Liljeborgia sp.2	+	+	+	-	-	+
Family Ampithoidae						
Ampithoe sp.	+	-	-	-	-	-
Family Isaeidae						
Isaeidae	+	+	-	-	+	-

Contd..........

Table 5.1						
Stations	**Rat 1**	**Rat 2**	**Goa1**	**Goa2**	**Kar 1**	**Kar 2**
Family Caprellidae						
Caprellidae (Unidentified)	-	-	+	-	-	-
Family Podoceridae						
Podoceridae (Unidentified)	+	-	-	-	-	-
Unidentified Amphipoda	+	-	-	-	+	+
Cumacea	+	+	-	-	+	-
Family Squillidae						
Squilla sp.	+	+	-	-	-	-
Decapoda						
Family Grapsidae						
Varuninae	-	-	-	-	+	+
Brachyurans	-	-	-	-	+	-
Family Penaidae	-	-	+	-	-	-
Gastropoda						
Family Potamididae						
Cerithidae sp.	-	-	-	-	+	-
Bivalvia						
Family Nuculanidae						
Nuculana sp.	-	+	-	-	-	-
Family Lucinidae						
Lucina sp.	-	-	-	-	+	+
Family Tellinidae						
Tellina sp.	+	-	-	-	-	+
Family Veneridae						
Unidentified Bivalvia	+	+	-	-	-	-

Table 5.2
SIMPER analysis based on group obtained from cluster and MDS ordination showing the species that contributed to the differences among the groups.

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	GROUP					
Avg. dissimilarity 78.7	Rat	Goa				
Mediomastus sp.	4386.72	81.4	30.07	3.71	38.17	38.17
Cossura sp.	1691.64	111	10.84	2.64	13.76	51.93
Prionospio pinnata	1900.32	740	8.37	1.64	10.62	62.55
Avg. dissimilarity 64.0	Rat	Kar				
Mediomastus sp.	4386.72	492.84	22.05	2.56	34.45	34.45
Notomastus sp.	4.44	1509.6	9.55	1.8	14.93	49.38
Cossura sp.	1691.64	279.72	7.86	1.92	12.28	61.66
Avg. dissimilarity 67.5	Goa	Kar				
Prionospio pinnata	740	2060.16	20.37	1.93	30.15	30.15
Notomastus sp.	74	1509.6	20.25	2.11	29.97	60.12
Mediomastus sp.	81.4	492.84	6.26	2.76	9.26	69.38

Table 5.3
Composition (%) of dominant species at various sampling location observed during the present study

Stations	Rat 1	Rat 2	Goa 1	Goa 2	Kar 1	Kar 2
Mediomastus sp.	30.55	41.96	4.66	2.44	8.14	12.77
Prionospio pinnata	17.86	15.91	40.93	25.61	36.46	50.00
Cossura sp.	10.93	16.60	7.25	1.22	6.73	4.33
Notomastus sp.	0.00	0.06	4.66	1.22	38.65	20.13
Aricidea sp.	2.47	2.48	3.11	8.54	0.16	0.65
Prionospio sp.	1.76	16.71	2.07	6.10	1.41	1.95
Eunice sp.	0.47	0.00	6.22	20.73	0.00	0.00
Ampelisca sp.	0.47	0.23	9.33	2.44	0.16	0.22

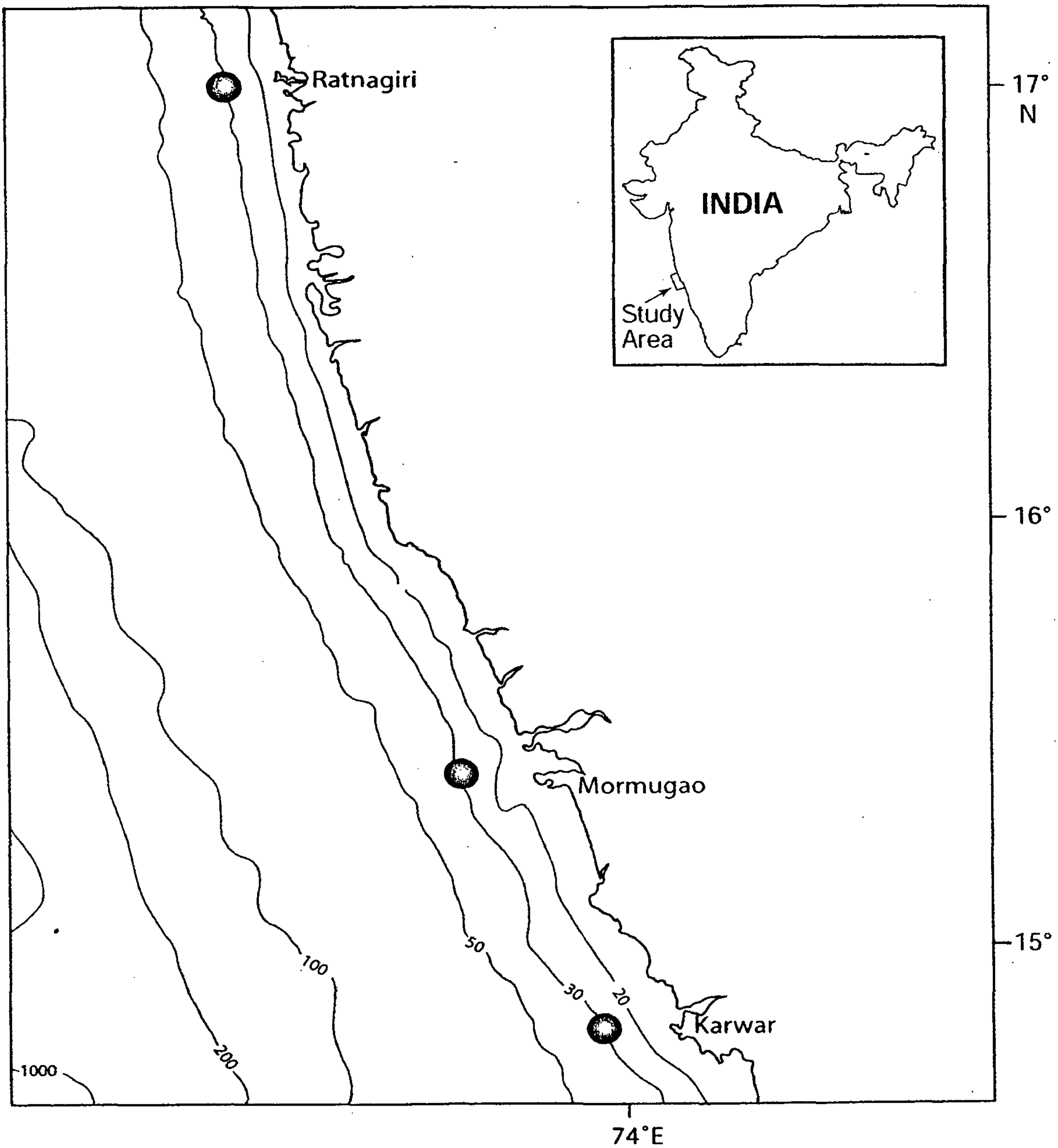


Fig. 5.1 Map showing the location of the sampling site

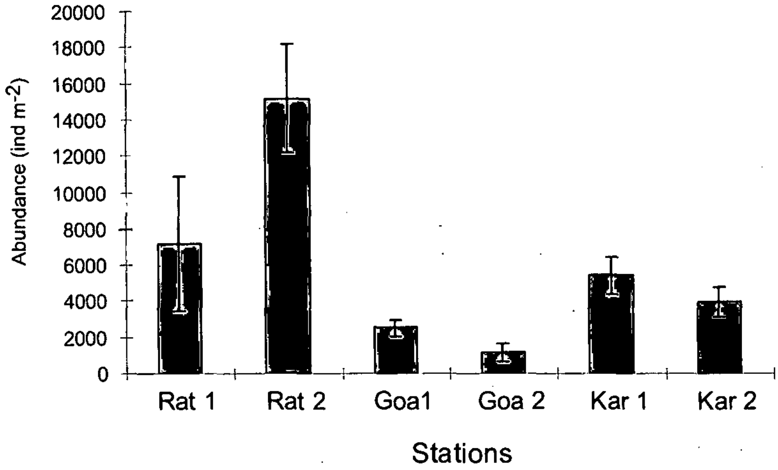


Fig. 5.2 Comparison of macrofaunal abundance in the three harbours

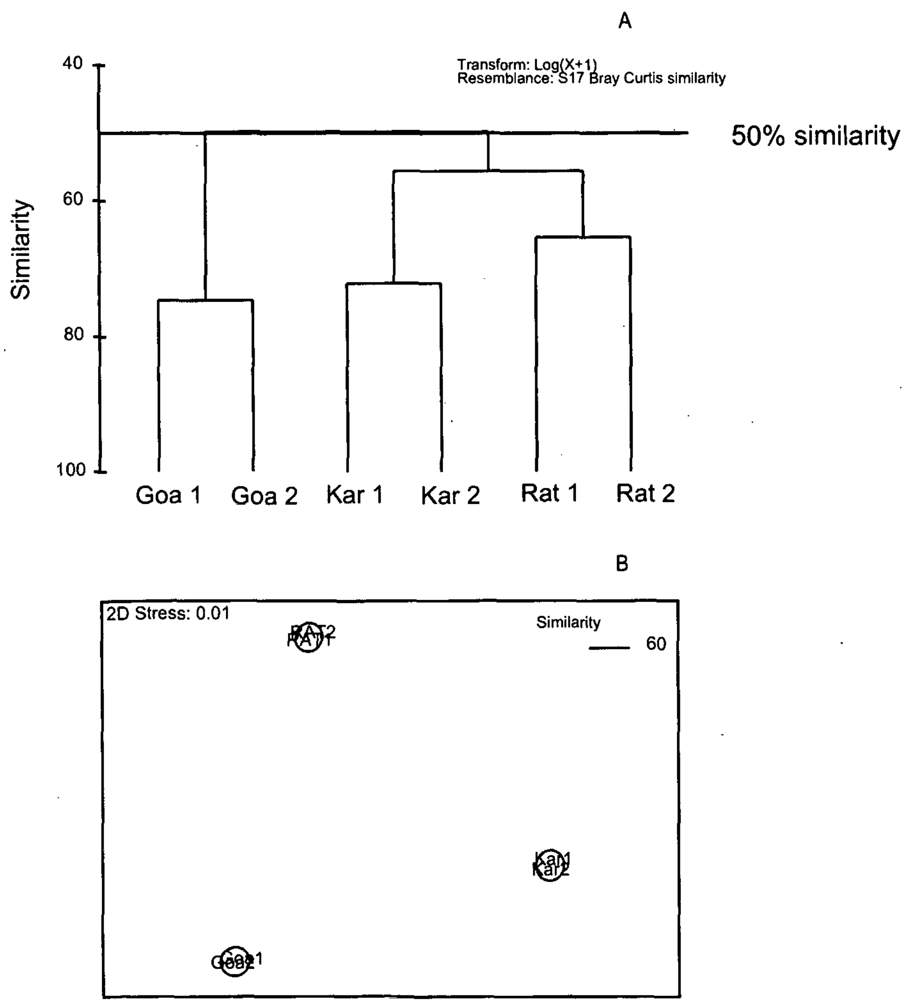


Fig. 5.3 Bray- Curtis cluster (A) and MDS (b) based on macrofaunal abundance in the study area

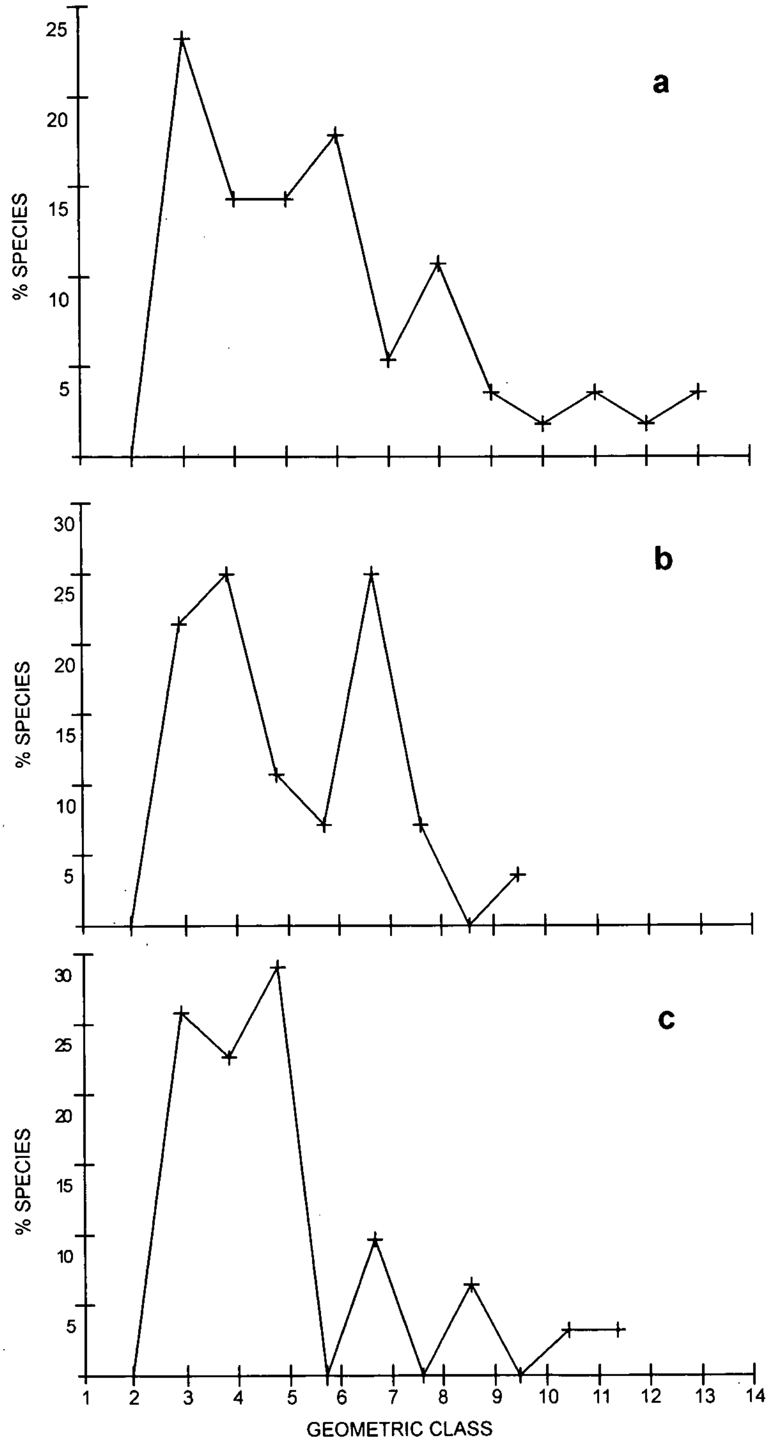
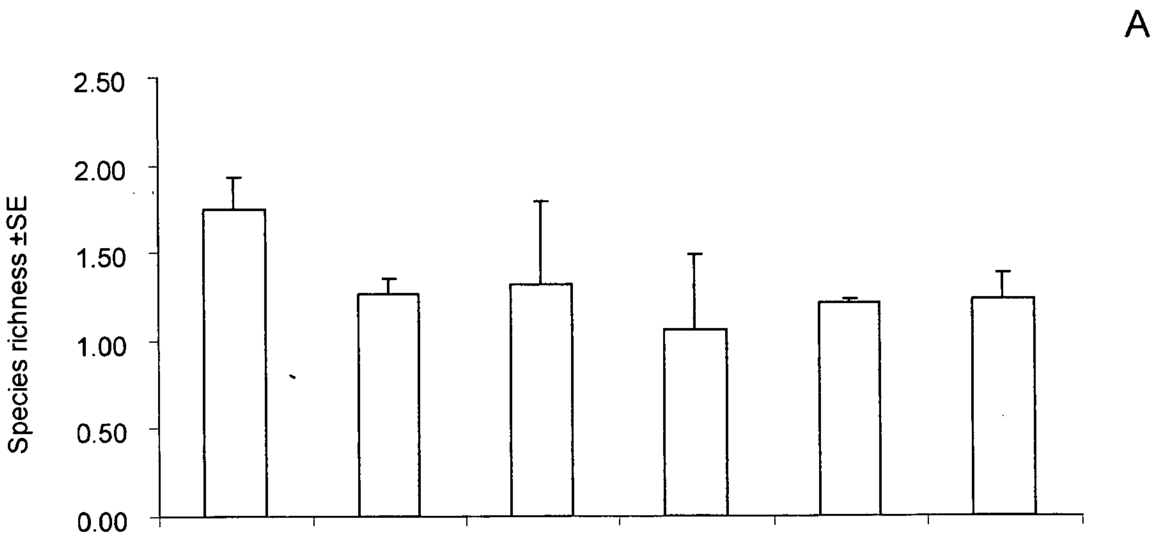


Fig. 5.4 Geometric class abundance for Ratnagiri (a), Mormugao (b) and Karwar (c).



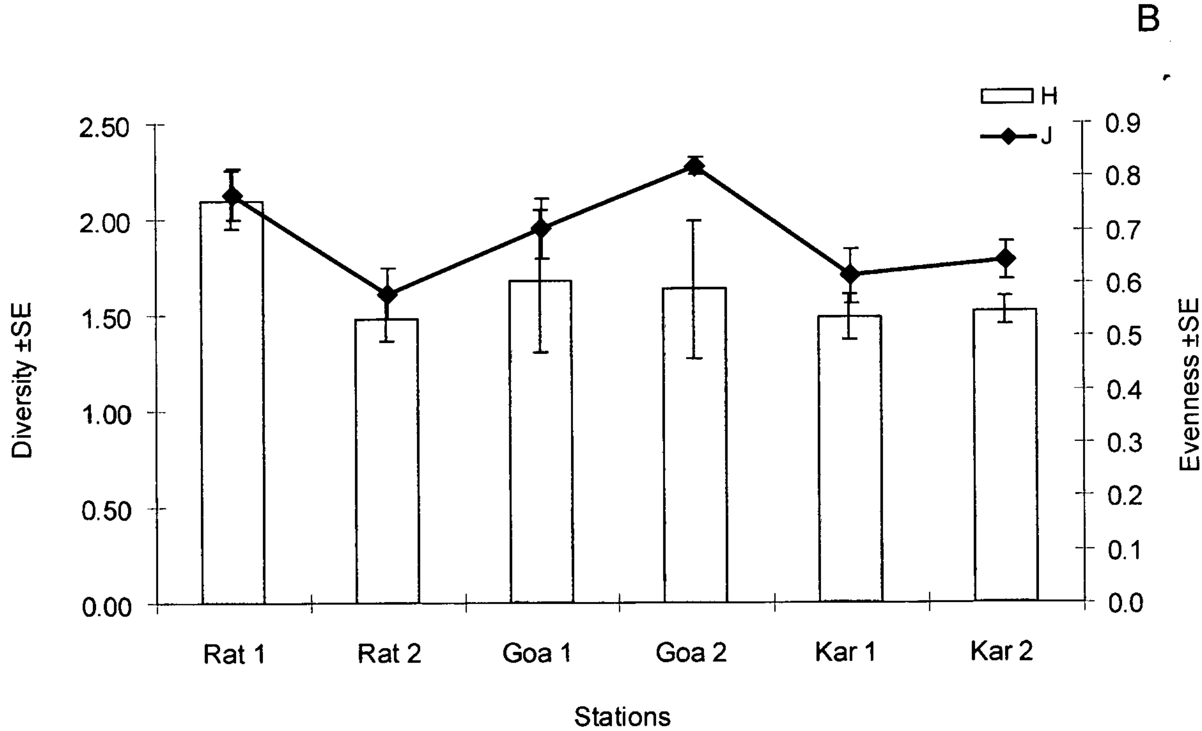


Fig. 5.5 Comparison of species richness (A), evenness and diversity (B) between the harb

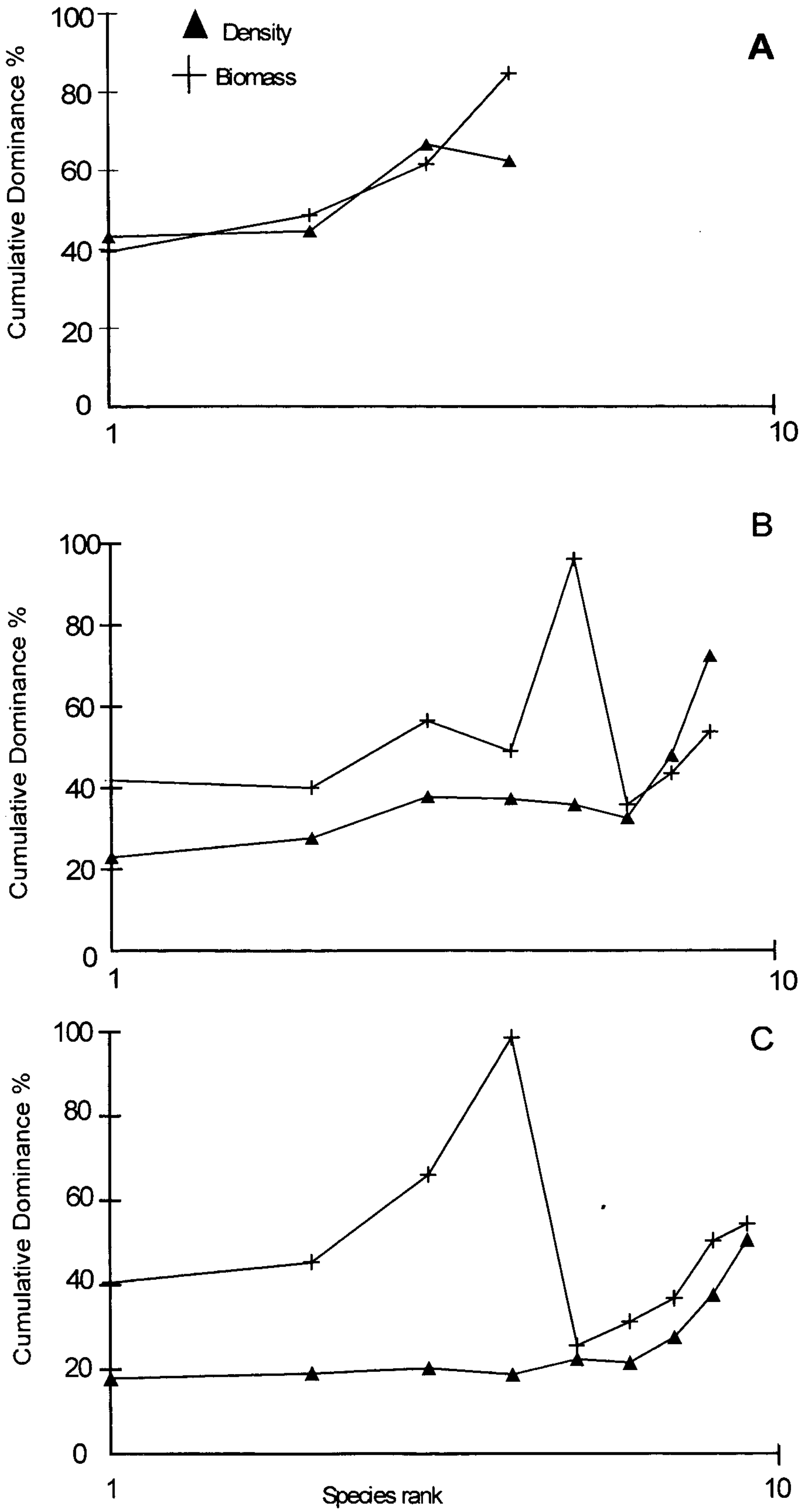


Fig. 5.6: Partial ABC curve of Goa (A), Ratnagiri (B) and Karwar (C)

Chapter 6

Vulnerability of Indian coast to oil spills

6.1 Introduction

Oil pollution of the marine environment has been an issue of considerable national and international concern. India relies heavily on the marine environment for trade and commercial operations. Further, two major oil choke points of the world- *Strait of Hormuz* and *Strait of Malacca* lies on the west and east coast of India. Due to the narrowness of these lanes, the routes are accident-prone. Moreover, imports of oil and gases are growing faster than the demand, particularly, in the developing countries led by China and India. World's demand for petroleum products has been estimated to go up from 84 mb/day in 2005 to 116mb/day in 2030 (Anon, 2006a). Risk of major oil spill occurring along the west coast of India is considerably higher today, as there has been a significant increase of all types of maritime trade (www.itpof.com). A major oil spill could cause widespread ecological damage, cripple or destroy marine commercial operations. Therefore, continued discharge of oil into the sea can pose a potential risk of severe pollution to the sensitive coastal ecosystem (Ansari and Ingole 2002; Ingole et al. 2006).

Goa, located along the central west coast of India also lies along the oil tanker route. Since 1994, four spills have been reported (Fig. 6.1) along the small coastal strip of Goa. In August 2005, large deposits of tar balls were reported from beaches in south Goa (www.nio.org). On 30th May 2006 the grounding of *MV Ocean Seraya* on the Karwar coast was reported to have affected the beaches in south Goa from Polem to Benaulim. In view, of the increased incidents of oil spills, it was felt necessary to analyse and discuss the impact of oil spills on the benthic community and coastal fishery. Therefore, the present study was carried out to discuss the potential impact of frequent oil spills on the macrobenthic community and marine fishery.

6.2 Materials and Methods

The data for the present study were compiled from various sources. The ITPOF (International Tanker Owners Pollution Federation) maintains a website on the oil psills all over the world. In addition, many countries maintain databases on tanker casualties and spills in their own waters that are generally freely accessible. To obtain an accurate data set, information from different sources were combined. However, other sources were also surveyed that contributed supplementary data or were used to achieve a high level of data consistency (Gregory 2006; Ingole et al. 2006; Ansari and Ingole 2002 and others).

6.3 Result and Discussions

Frequent, occurrence of tar balls and oil pollution along the beaches of Goa is a major threat to the tourism, which is one of the main employments generating industry in the state. About two million tourists (domestic and foreign) visit Goan beaches every year, which accounts to 12% of all the tourist arrival of India. There are around 439 medium and 11 five star hotels in Goa (EDC, Govt. of Goa, 2005). It speaks for the volume of domestic and international tourists visiting the state. Oil spills not only affect the immediate beauty of the beaches but it is also known to affect the coastal ecology and fishery on long-term basis (Ingole et al. 2006).

6.3.1 Vulnerability of Indian coast to oil spills

In contrast to increase oil consumption, resulting in increase maritime transportation, incidents of accidental oil spill has shown a decrease globally since the 1970s. Tanker spills, annually accounts to 12% of the oil entering the sea and a total of 531 spills have been reported internationally from 1979-2004 (Burgherr 2006). Among the accidental tanker spills, 34.4% occurred due to grounding of vessel and 28.3% due to collisions (Burgherr 2006). According to Clarke (1986) most of the oil affecting marine ecosystem is derived from tanker operations and accidents. However, compared to the decrease in oil spills incidents globally, the number of tanker spills/accidents has increased along the Indian coast. Of the total observed spills, 70% were reported from the west coast of India (Table 6.1; Fig. 6.2). Moreover, the data also revealed that the majority of the spills have occurred during the SW monsoon period (Table 6.1). Model studies, based on historical data of winds and surface currents indicate that during the SW monsoon along the shore surf currents develops an easterly shoreward component (Gouveia and Kurup 1977; Kurup 1983) resulting in rough weather conditions. This makes the west coast vulnerably exposed to any oil spills in the Arabian Sea during SW monsoon. The spawning periodicity of majority of marine organism and commercial fishes coincide with monsoon season so that their larvae could utilize the abundant planktonic food resulting from the seasonal upwelling (Warren 1992). Therefore, oil spills occurring during the critical life stage of marine organism may have long-term impact on their recruitment.

from the seasonal upwelling (Warren 1992). Therefore, oil spills occurring during the critical life stage of marine organism may have long-term impact on their recruitment.

The study on the impact of *MV Ocean Seraya* did not show direct impact of oil spill on the intertidal macrobenthic community (Gregory 2006), even though, PHC in the beach sediment were high (13 µg g^{-1}) at the site closest to the spill (Polem; Fig 6.3 a). Further the organic carbon values were also high at Polem (Fig 6.3 b). The average sediment hydrocarbon concentration along the Goa coast was observed to be 7.1 µg g^{-1} (Fondekar et al. 1980). Experimental evidence suggests that about 56% of spilled oil becomes adsorbed onto bottom sediment (Knap and Williams 1982) where oxidation may take place over several years (Thomas 1993). Oil stranded from *Exxon Valdez* persisted for >10yrs on some boulder –armoured beaches bordering the Gulf of Alaska. These sites are 300-700 km from the spill and the oil was chemically similar to 11-day oil of *Exxon Valdez* (Irvine et al. 2006). Thus, the degree of oil pollution in the marine environment may be more accurately assessed by measuring oil in the sediment (Sen Gupta et al. 1993) and impact of oil spill can be very well evaluated through benthic fauna (Ingole et al. 2006).

Sediment-associated oil from major spills has been shown to persist in the marine environment for years, and can be re-released in potentially toxic concentrations (Seip 1984). Dauvin (1998) and Ansari and Ingole (2002) suggested that intertidal benthic communities are generally sensitive to oil spills, but the effects of oil pollution strongly depend on the proportion of hydrocarbon-sensitive species, especially crustaceans. While discussing the short- and long-term impact of oil spill from grounded *MV Sea Transporter* on the intertidal meiobenthic communities, Ansari and Ingole (2002) indicated that short-term effect of oil spill was very severe as most of the microscopic organisms were eliminated from the intertidal habitat. Strong wave action on the open beach and manual beach cleaning by the local administration assisted in reducing the PHC content in sediment. This resulted in faster recovery of meiobenthic communities. On the other hand, while studying the impact of oil spill from another grounded vessel *MV River Princess*, Ingole et al. (2006) demonstrated that relatively small scale but persistent oil spill not only reduced benthic standing stock (abundance and biomass) but also some of the oil sensitive species were eliminated from the intertidal habitat. PHC concentration was higher at the groundec site (Candolim) and showed further increase from 43 to 58 μg g^{-1} (Ingole, *persona communication*; Fig. 6.4a). Increased PHC's in sediment was due to the possible leakage from the grounded *MV River Princess* vessel (Ingole et al. 2006). Further hydrocarbon values were highest in the sediment depth of 6-8 cm (Fig. 6.4b). The macrobenthic species number of Candolim showed decrease from 27 (Harkantra and Parulekar 1984) to 11 (Ingole et al. 2006).

The vulnerability of organisms to oil is related to seasonal changes in their distributior and abundance. Accordingly, for a particular species, spilled oil may have less impact a one part of the year than another. Monsoon is the recruitment period of most of tropica benthic organisms and commercial fish. As it is evident from the present study, majo recruitment of *E. holthuisi* occurs during monsoon as the *Emerita* population was dominated by juveniles (> 80%). More than 90% of the benthic organisms have planktonic larvae (Thorson 1957). Generally the effect of oil spills is first observed in the pelagic organism. An oil spill is not stationary in the water column, it spreads over large surface area under the influence of winds (monsoonal or otherwise), during which i affects the pelagic organisms.

There is an increasing data of the susceptibility of early developmental stages to oi especially at the cellular and sub-cellular level, sometimes at substantially lowe concentrations (Malins 1982). The cumulative impact of *North Cape* oil on winte flounder embryos was a reduction of 51% in the number of embryos surviving to th larval stage (Hughes 1999). Naphthalene and phenanthrene, both light weight PAHs, ar among the most toxic fractions of oil to marine fish (Gundersen et al 1996). When No. oil is exposed to sunlight, more persistent and toxic compounds are produced (Larsc 1977) and the peroxides produce mutation. Many of the commercial fishes exploit th near shore area for spawning and development of sensitive embryonic and larval stage This could work against these species when the area becomes contaminated with tox material such as oil. Survival through planktonic development stages is believed to t the most important event controlling abundances of marine organism. Also the ea

Benthos is the major food sources for demersal fisheries and benthic production shows strong seasonality; consequently any impact on benthos will affect the demersal fishery production of the area. Analysis of benthic biomass distribution and demersal fish showed a positive correlation and high biomass area was found supporting greater density of bottom fishes (Harkantra et al. 1980; Ansari et al. 1995).

The marine fish landing for the year 2004 was 63, 5094 tonnes along the west coast contributing to ≈ 73% of the total marine fish catch of the country (Anon 2006b). Fish catches are increased considerably in last few decades. However, the increase has been attributed to mechanization and phenomenal increase in the number of fishing trawlers as well as advancement in gear technology (Ansari et al. 2006). Landings of major fisheries resources in the Indian Ocean region have declined significantly. Overexploitation is attributed to be the main cause of declined fish catches worldwide, which may be further affected by frequent oil spill occurrence.

Significant changes in commercial fish stocks do take place in inshore areas, although attempts are not usually made to link them with any single pollutant (McIntyre 1968). However, oil spills could be one of the reasons for fluctuation in total fish catch as hydrocarbons can greatly reduce the individual organism's chances for survival (Rosenthal and Alderdice 1976) and accordingly population changes are of potential concern. McIntyre (1968) considers that fisheries on the continental shelves are at greater risk than those offshore, and that effects on shallow coastal intertidal areas may last for years.

Apart from accidental spills, oil pollution occurs during routine operations such as loading, discharging and bunkering, which are normally carried out in ports or at oil terminals. Concerns have arisen recently about the number of illegal discharges from the large volume of shipping within the region. After evaporation of the lighter fractions of oil and photoxidation, the heavier fraction gradually forms into tar balls. Driven by winds and current, these tar balls are deposited on the beaches. Periodic tar ball and raw oil pollution is observed on all the major beaches, mainly during the onset of monsoon and sometimes throughout the year. The life of tar balls in the sea varies from 33-58 days, while on the beaches it is not yet know. However due to the half yearly changes in surface circulation, these tar balls are deposited along the beaches of India, including

Goa. Estimates from 2 years data gave a figure of 40 tonnes as the yearly deposit of tar balls along the beaches of Goa (Sen Gupta et al. 2002). In August 2005 oil spill from unknown source caused deposit of tar along the major tourist beaches and heavy mortality of beach communities (Ingole 2005; www.nio.org). Threats of oil contamination in the sea and the coastal area as a result of petrol related activities and the usage of petroleum and petroleum products is very serious since this could cause irreparable damage to the marine ecosystem, thereby affecting the socio-economic status of the population who depend on the coastal resources for their livelihood.

Further, residual oil from oil spill carpet the seabed and remains in contact with seabed for longer time, thus, have long-term effect on benthic environment. The increasing trend of oil spills around the coast could certainly have a negative impact on the marine community, as observed earlier and the economy in terms of fishery and tourism. A comprehensive long-term investigation is therefore required to study the impact of oil pollution on coastal ecology that will help in conserving the coastal biodiversity.

6.4 Conclusion

India only had relatively minor oil spillages in its coastal waters, primarily from tanker accidents. The possibility however of a major oil spill occurring along the Indian coast is considerably higher today as there has been a significant increase of all types of oil tankers/bulk carriers/container ships passing through the Indian Ocean. Further, India also depends on sea transport for majority of its trade. Coastal areas all over the world have been reported to be damaged from pollution, thus having a significant affect on marine ecosystem, in particular the fisheries. Therefore, control of aquatic pollution has been identified as an immediate need for sustainable management and conservation of the existing fisheries and aquatic resources.

Table 6.1:
Major oil spills on Indian coast since 1970* Abbreviations: FO: Fuel Oil; HO: Heavy Oil;

Date	Qty. Spilled (T)	Position	Vessel
Aug '70	15,622 / FO	NW coast of India(off Kutch)	Greek oil tanker 'Ampuria' .
Jun '73	18,000 / LDO	NW coast of India of Arabian Sea	MT Cosmos Pioneer
Sep '74	3,325 / FO	Kiltan , Lakshadweep.	American Oil Tanker 'Transhuron'
Jul '76	29,000	Off Mumbai	Crestan Star
June '79	11,000	Cochin	Aviles
1982	NK	West Coast	Sagar Vikas
Oct '88	1000	Bombay Harbour, Maharashtra	Lajpat Rai
1989	NK	West Coast	SEDCO 252
Jun '89	5500	795 NM SW of Mumbai	MT Puppy
Aug '89	NK	Bombay Harbour,	ONGC Tanker
Aug '89	NK	Saurashtra Coast, Gujarat	Merchant Ship
Aug '89	NK	Bombay Harbour,	NK
Mar '90	NK	NW of Kochi, Kerala	Merchant Ship
Sep 91	692/FO	Gulf of Mannar, Tamil Nadu	MT Jayabola
Nov '91	40000/Crude	Bombay High, Maharashtra	MT Zakir Hussain
Feb '92	Tanker Wash	40 NM S of New Moore Island, Bay of Bengal	Unknown
Apr '92	1000/Crude	54 NM West of Kochi, Kerala	MT Homi Bhabha
Aug '92	1060/SKO	Madras Harbour, Tamil Nadu	MT Albert Ekka
Nov '92	300/FO	Bombay Harbour, Maharashtra	MV Moon River
Jan '93	40000	Off Nicobar	Maersk Navigator
Mar '93	NK/Crude	Off Narsapur, Andhra Pradesh	ONGC rig, Kumarada
Apr 2 '93	110/Crude	Bombay Harbour, Maharashtra	MT Nand Shivchand
May '93	90/FO	Bhavnagar, Gujarat	MV Celelia
May '93	6000/Crude	Bombay High, Maharashtra	Riser pipe rupture
Aug '93	260/FO	Off New/Mangalore	MV Challenge
Oct '93	90/Crude	Cochin Harbour, Kerala	MT Nand Shivchand

Contd........

Date	Qty. Spilled (T)	Position	Vessel
May 94	1600/Crude	Off Sac Romanto	Innovative -1
May 12	-/FO	360 NM SW of Porbandar.	MV Stolidi
Jun 5	1025/Crude	Off Aguada Lighthouse, Goa	MV Sea Transporter
Jul '94	100/FO	Bombay Harbour, Maharashtra	MV Maharshi Dayananad
Nov '94	288/HO	Off Madras, Tamil Nadu	MV Sagar
Mar '95	200/Diesel	Off Vizag, Andhra Pradesh	Dredger Mandovi - 2
Sep '95	-/FO	Off Dwarka, Gujarat	MC Pearl
Nov '95	Tanker Wash	Eliot beach, Chennai.	Unknown
May '96	370 FO	Off Hooghly River.	MV Prem Tista
Jun 96	120/FO	Off Prongs Lighthouse. Maharashtra	MV Tupi Buzios
Jun 96	132/FO	Off Bandra, Maharashtra	MV Zhen Don
Jun 96	128/FO	Off Karanja, Maharashtra	MV Indian Prosperity
Jun '96	110/ FO	Off Worli, Maharashtra	MV Romanska
Aug 96	124/FO	Malabar Coast, Kerala	MV Al-Hadi
Jan 97	Tank Wash	Kakinada Coast. AP	Unknown
Jun 97	210/FO	Off Prongs Lighthouse, Maharashtra	MV Arcadia Pride
Jun '97	NK	Hooghly River, West Bengal	MV Green Opal
Sep 97	Naptha, Diesel Petrol	Vizag, Andhra Pradesh	HPC Refinery
Aug '97	70/FO	Off Mumbai, Maharashtra	MV Sea Empress
Jun '98	20/Crude	Off Vadinar, Gujarat	Vadinar, SBM
Jun 98		Off Porbandar, Gujarat	Ocean Barge
Jun 98		Off Veraval, Gujarat	Ocean Pacific
Jul 98	15/FO	Mul Dwarka, Gujarat	Pacific Acadian
Jul 00	-	Off Sagar Island, West Bengal	MV Prime Value
Sep '00	-	Off Fort Aguada, Goa	MV River Princess

Contd.........

Date	Qty. Spilled (T)	Position	Vessel
Dec '00	1/FO	Bombay Harbour, Maharashtra	MV Stonewall Jackson
Jun '01	-	Vadinar, Gulf Of Kachchh,	Not Known
Jul '01		Hooghly River, West Bengal	MV Lucnam
Aug '01		SBM Vadinar, Gujarat	
Sep '02		220 NM Off Pt Calimare	MV Hiderbahy
Apr '03	1.8T/ light crude oil	05 miles Off Kochi, Kerala	MT BR Ambedkar
May '03	4 NM Oil	Off Haldia, West Bengal	MV SEGITEGA BIRU
Aug '03	300/Crude Oil	ONGC Rig (BHN), Maharashtra	URAN Pipe Line
Feb '04	01/Crude Oil	ONGC Pipe line at MPT Oil Jetty	Crude Oil Transfer.
Oct '04	0.56	Berthed - MPT – 8, Goa	
Mar '05	110	Off Aguada Lighthouse, Goa	MV Maritime Wisdom
Jun '05	49,537/Cargo & 640/FO	Vishakhapatnam Port	MV Jinan VRWD - 5
Jul '05	350 cu m Base Lube Oil	Mumbai Harbour	Dumb Barge Rajgiri
Jul '05	33 FO	NE of Paget Island (N. Andaman)	MV Edna Maria
Jul '05	80	Of Prongs Lighthouse, Off Mumbai	OSV Samudra Suraksha
Aug '05	-	9 NM Off Tuticorin	MV IIDA
Sep '05	100	Off Vishakhapatnam	MV Royal Ocean 2
May '06	650 /FO	Oyster rocks, Karwar	MV Ocean Seraya
Aug '06	4500	Grear Nicobar Island	Bright Artemis

***Source:** Indian Coast Guard (www.indiancoastguard.nic.in)

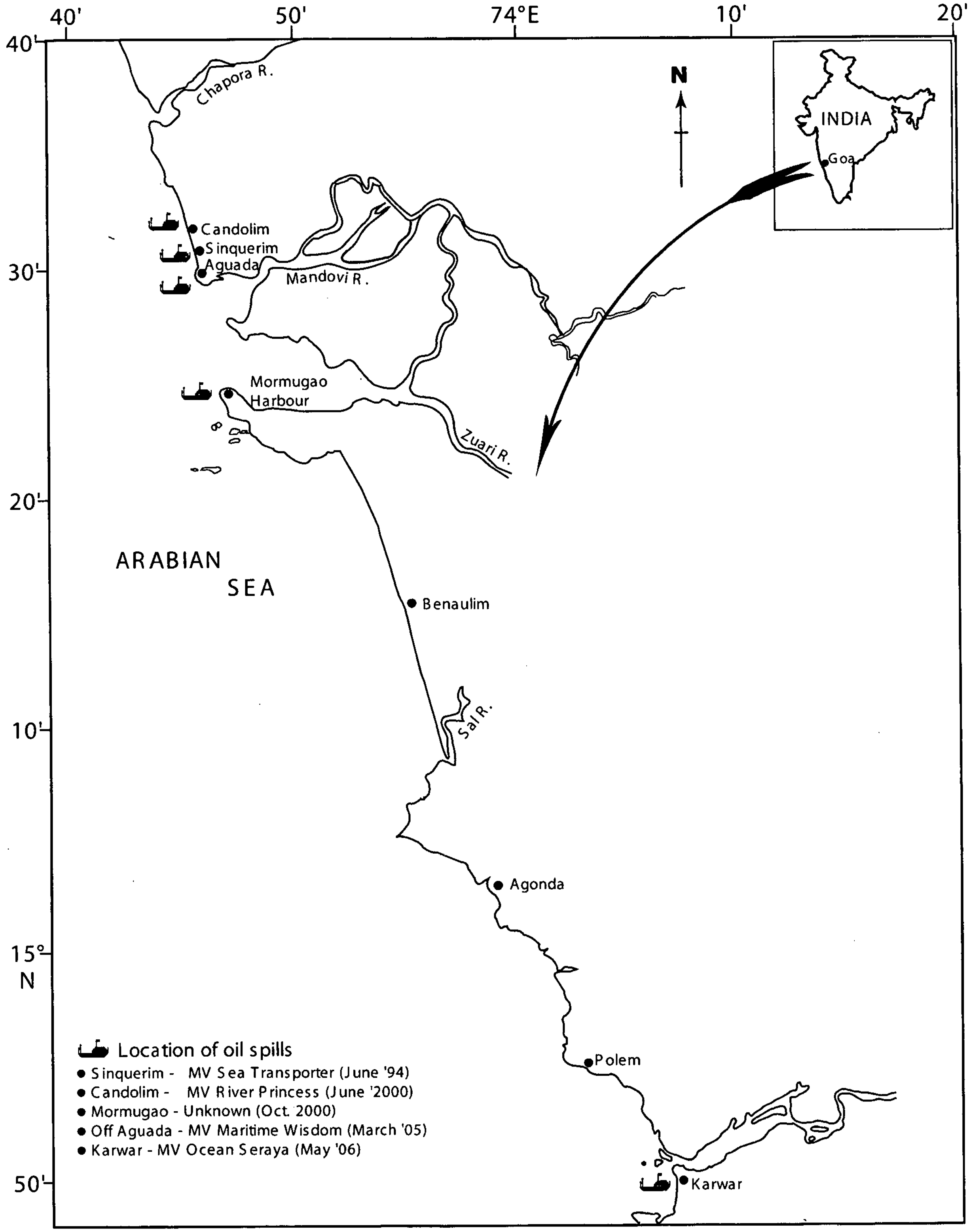


Fig 6.1 Map showing the tanker accidents along the Goa coast

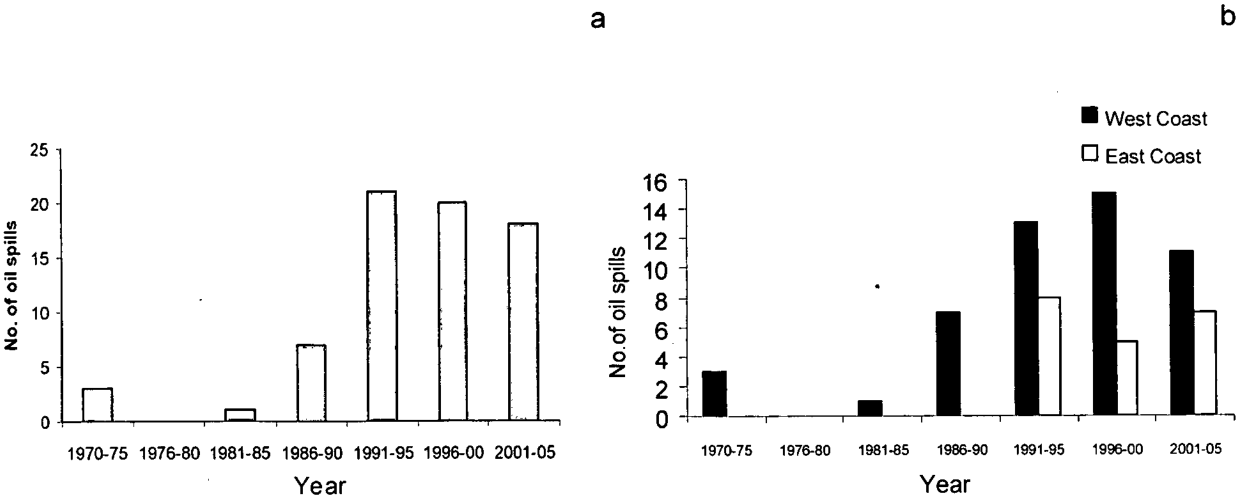


Fig 6.2 Number of ol spills in India (a) comparsion of east and west coast of India (b)

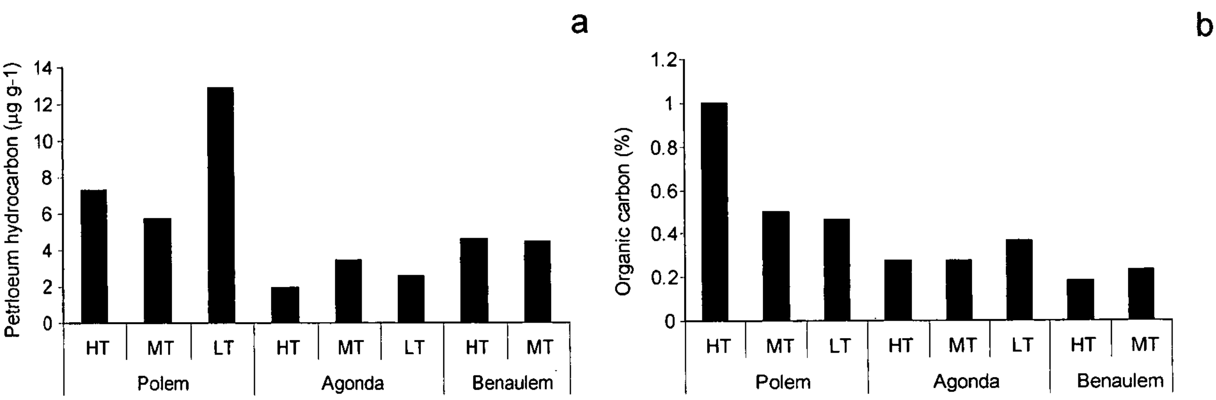


Fig 6.3 PHC (a) and Organic carbon(b) concentration in the study area
* Source: Gregory 2006

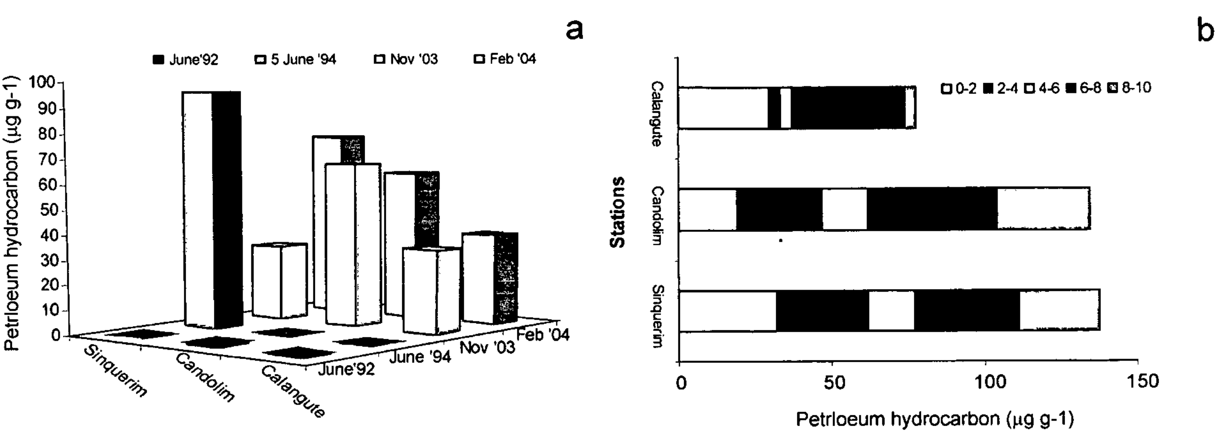


Fig. 6.4 Variation in PHC concentration (a) and vertical distribution of PHC (b) at Sinquerim-Calangute- Candolim
*Source : Ingole et al 2006 & Ingole (personal Communication)

Chapter 7

Ecology of *Umbonium vestiarium* and macrofauna of the intertidal region of Kalbadevi

7.1 Introduction

Sandy beaches comprise approximately three-quarters of the world's shorelines (Bascom 1980). They harbour a diverse and abundant fauna (Brown and McLachlan 1990). This zone is considered as the most productive with the greatest diversity of life of any ecological area of the world. Moreover, the coastal zones host some of the largest and richest shoreline placers.

Indian coasts host some of the largest and richest shoreline placers. Distribution of heavy mineral concentrations in the Konkan coast has been reported (Siddiquie et al. 1979). According to Krishnan and Roy (1945), Mane and Gawade (1973) and Siddiquie and Rajamanickam (1979) Deccan traps are the main source for these minerals. The entire coastline of Ratnagiri district in Maharashtra was explored for heavy mineral potential (Gujar et al. 1988, 2001). The heavy mineral concentration varies from 20-83% by weight. Heavy mineral reserves of 4.9 Mt containing 3.04 Mt of ilmenite have been estimated from these areas. The detail exploration may enhance the resource base of ilmenite and is considered to be one of the potential deposits for exploitation on the west coast. Ilmenite is an economically important ore of titanium. Titanium alloys because of their light-weight ability to withstand high temperature and resistance to salt water have found applications in aeronautics, shipping and medical engineering.

The intertidal beach at Kalbadevi along the Ratnagiri coast is one of the highly potential site for ilmenite mining (Plate 7.1 a-d). Moreover, the Konkan coast is known for its rich biodiversity including the fishery resource (Ingole et al. 2008). On contrary to the subtidal areas, the intertidal benthic fauna of Ratnagiri district has been paid very little attention and in particularly the Kalbadevi beach-a potential area for placer mining.

Molluscs are an important component of the intertidal macrobenthic community. Bivalves such as mussels and clams form substantial parts of coastal diets and the shells are often used in handicrafts and other purposes. During the preliminary survey of the Kalbadevi Bay, it was noticed that a small trochid gastropod, ***Umbonium vestiarium*** (Linne 1758) dominated the area. *U. vestiarium* play a role in the coastal economics because of its shells is available in wide assortment of bright colours and therefore used as curios (Jones, 1978). Additionally, *U. vestiarium* is consumed by the locals and considered a delicacy. Literature on *U. vestiarium* is confined to studies related to the reproduction and feeding habits from Malaysian shores (Berry, 1986, 1987; Ong and Krishnan, 1995). Despite its ecological and economic importance, very few studies have been conducted *U. vestiarium* population in India (Kalyansundaram et al. 1974; Rajagopal 1983). This study aims at initiating the process of addressing the void that currently exists in *U. vestiarium* related research.

Depletion of mineral resources on land has made man view the ocean as a last frontier for raw materials. Beach minerals such as ilemnite, rutile, garnet, zircon and monazite which are increasingly used in conventional and high tech applications are in great demand in the global market, as a viable substitute for them is neither available nor insight in the foreseeable future.

One of the greatest challenges when determining the impact benthic communities face from mining is the lack of baseline data and overall context in which benthic communities can be compared. Thus, efforts are needed in assessing diversity and the processes that affect their abundances. Therefore, the aim of this study is to (1) understand the ecology of the most abundant macrofauna, *U. vestiarium* (2) Spatio-temporal variability of the macrofauna and (3) zonation pattern of the macrofauna on the intertidal beach.

7.2 Materials and Methods

7.2.1 Study Area

The Kalbadevi beach (17°02' 68" to 17° 04' 07"N latitude) and (73° 16' 93" to 73°17' 32" E longitude) is ≈ 5km long and ~250m wide (Fig. 7.1). It is an arcuate bay invaded by estuaries in the north (Are creek) and south (Kalbadevi creek). Occurrence of ilmenite placers in the beach and estuaries and their offshore extension have been reviewed by Gujar et al (2001). Siddiquie et al. (1979) indicated the extension of placers to be about 9-12 m in depth and from 2 to 5 km offshore. According to them, the heavy minerals (magnetics, non-magnetic fractions and ilmenite) are concentrated with sands at stream entrances, along the shore, and with silts in the center of the bays or offshore. Further, due to the arcuate shape of the bay, the northern part of the beach experiences pounding by powerful waves from the west and south-west during the monsoon season leading to concentration in the area. The inferred reserves of ilmenite to a depth of 1 m are estimated to be 2 MMT (Valsangkar 2007).

The vegetation in the area comprised of sand dune, seaweeds and mangroves (plate 7.1 e-f). According to Dhargalkar (unpublished data), the sand dune vegetation comprised of 23 species. A total of 18 species of drifted sea weed were recorded at southern transect (Anon 2004b) indicating seaweed beds in the sub tidal region.

7.2.2 Field Sampling

Seasonal macrobenthic sampling was conducted along the ten transect covering entire intertidal expansion. Monsoon sampling was conducted during August 2004 and September 2005, post monsoon during November 2004 and premonsoon during February and May 2004 and April 2005. Each transect was sub-divided into three zones viz, high-, mid- and low tide. Sediment samples for macrofauna were collected in duplicate using quadrant (0.625 m^2; Plate 7.2). Sediment was sieved on 500µm and materials retained on the sieve were preserved in 5% seawater formalin-Rose bengal.

To study the population dynamic of *U. vestiarium* the samples were collected with the quadrant and stored at -20°C till further analysis.

To study the intertidal zonation, the beach was divided into three different transects i.e. North, Central and South, equally spaced along the beach and oriented perpendicular to the waterline (Fig 7.1). Samples were collected from high to low tide at 10m interval using quadrant and processed as above. Sediment samples were also collected using a core for estimation of sediment texture, chlorophyll content and organic carbon.

7.2.3 Laboratory Analysis

The population of *U. vestiarium* from Kalbadevi was comprised of eleven different colour pattern and grouped accordingly. The categorization was based on a combination of colours and patterns present on shells. Maximum diameter was measured with a vernier caliper. Each animal was weighed to obtain the total weight, meat weight and dry weight after drying in the oven.

The macrobenthic samples were processed as mentioned in Chapter 3. Samples for organic carbon and chl *a* were anaslysed as mentioned in chapter 2. Grain size was carried out by sieving method (Folk 1968).

7.2.4 Data Analysis

All the data was initially processed using Microsoft Excel. Grain size analysis was processed using Gradistat 5. The biological data were subjected to analysed by Primer 6 and Statistica 6 (Chapter 3).

7.3 Result

7.3.1 Environmental Characteristics

The details of granulometry are given in Table 7.1. The D_{50} for the area ranged from 161- 1394 µm. Percentage of fine sand was more on the north and south transect; whereas percent of coarse particle was higher on the central transect. Sediment texture showed seasonal variation in grain size. It was found to be coarser from pre monsoon to monsoon season. ANOVA analyses showed significant variation in sediment texture between season ($p<0.001$) and tide ($p<0.01$).

Sediment chl *a* was low in the area (Fig. 7.2). The stations located in the south (stn 7 to 10) showed relatively higher chl *a*. Chl *a* was high at Stn 10 and ranged from 0.22- 0.28 $\mu\ g^{-1}$. Seasonally, high values were reported during post monsoon. Sediment organic carbon showed significant seasonal variation (Fig. 7.2b; $p<0.001$) with high in pre monsoon (0.42%) and low during monsoon (0.1%). Spatially, average OC was high at stn 10 (0.45%) and low at stn 2 (0.17%). OC value showed a non significant variation between stations.

7.3.2 Ecology of *Umbonium vestiarium*

7.3.2.1 Polymorphism in *U.vestiarium*

The specimens *of U. vestiarium* were grouped into eleven types depending on their different colour patterns (Table 7.2; plate 7.3 a-d). Overall, the colour pattern 3, 6 and 8 were found to be the most abundant constituting 42% of the total *Umbonium* population at Kalbadevi. The colour pattern 4, 10 and 11 accounted for 12% of the total population. The two sampling sites individually revealed the same colour pattern except for type 01 which was more abundant in South (10%).

7.3.2.2 Distribution and abundance

The distribution of *U. vestiarium* on the Kalbadevi beach was restricted to southern and northern transect and with varied abundance. In the south, seasonally the abundance was high during monsoon (3563 ind m^{-2}) and low during pre monsoon (2344 ind m^{-2}). Vertically, the species occupied the entire intertidal expansion except high tide (Fig. 7.3a). It was present at 30 m from the high tide mark to the low tide. In general, the presence of *U. vestiarium* was more pronounced between the mid- and low tide. The abundance was higher at low tide region during late monsoon (32 - 9072 ind m^{-2}; Fig. 7.3a). The abundance and distribution of this species in north showed significant variation compared to the south (Fig. 7.3b). The average abundance in the northern transect ranged from 557-997 ind m^{-2} during the post- and pre monsoon respectively. The *U. vestiarium* was distributed from mid tide to low tide zone during pre monsoon (16-7216 ind m^{-2}) and monsoon (64-2688 ind m^{-2}). During the post monsoon, it was restricted only to the mid tide region (Fig 7.3b) and the abundance ranged between 48-2688 ind m^{-2}.

7.3.2.3 Morphometry of *U. vestiarium*

The size class was divided in to 1mm size class. A total of seven size classes were observed. In south, the population size ranged from 6-13 mm, whereas in the north it was from 7-14mm (Fig. 7.4a). The smallest sized specimens were in southern transect during monsoon (August 2004 and September 2005; Fig. 7.4). The size ranged from 6.0-12mm. The smallest size class 6.0-7.0mm made to 5% of the population whereas, 77% of the population was in the range of 8-11mm in monsoon. A similar trend was observed during September 2005 when 93% of the population was in the size of 8-12 mm. During post- and pre monsoon, majority of the population (> 60%) was in the size class of 9-12mm. The gastropod population in the north showed a different pattern (Fig. 7.4b). The smallest size class was of 7-8mm and the smallest individual of 7.1mm was recorded during April 2005. In general, 50% population during April and September 2005 was in the 8-9mm size class. The 11-12 mm size class was dominant during May, August and November 2004. The largest specimens recorded in the north were 13.8 mm which was collected in November 2004.

The average weight of *U. vestiarium* ranged from 0.21-0.54 g for population in the North. Maximum mean weight was observed during November and minimum during

September. Meat weight was lower in April (0.049 g) and higher in November (0.115 g). In the south, the average total weight varied from 0.29-0.37 g. Average meat weight ranged from 0.06-0.074 g during August and November, respectively.

7.3.3 Spatio-Temporal variability of macrobenthic community

7.3.3.1 Macrobenthic community

The intertidal macrobenthic community was represented by 56 taxa belonging to 4 phyla and 8 classes (Table 7.3). The average abundance in the area ranged from 1217- 2687 ind m^{-2}. The higher abundance was observed during post monsoon and low value was during monsoon (Fig.7.5). ANOVA and post hoc test detected significant temporal variation in faunal abundance ($p<0.01$) and the differences between different tide level were also significant ($p<0.0001$). The interaction of season and station was also statistically significant ($p>0.05$).

The faunal group showed temporal variation (Table 7.4). Gastropoda dominating the fauna abundance during pre monsoon (56%) and monsoon (34%). The post monsoon community was dominated by polychaetes (42%). Overall, polychaetes dominated the abundance and made to 31.5% of the total fauna. Gastropoda (27%) was next in abundance followed by Crustacea (26.7%). Other groups Nemertea, Nematoda and Oligochaeta contributed to the remaining 15% of the abundance. Plate 7.3 e-h represents some of the macrofauna collected from Kalbadevi beach.

U. vesitiarium (27%) was the most dominant species. The distribution of *U. vestiarium* was restricted to the north (stn 1-3) and south (stn 8-10) of the study area. *Mediomastus* sp. made to 10% of the total abundance of the area and was the most dominant polychaetes species (Table 7.5-7.7). Like the other species, *Mediomastus* sp. also showed seasonal variation with high abundance during the post monsoon and was absent during monsoon. Abundance of *Mediomastus* sp. ranged from 0- 32 ind m^{-2} and 0-1691 ind m^{-2} during post monsoon. The high abundance was seen at stn 7. The spionid polychaete, *Nerine cirratulus* was next in dominance (6.4%). High abundance was reported during post monsoon (11-1679 ind m^{-2}) and low during monsoon. *Scoloplos marsupialis* (3.5%), *Levinsenia* sp. (3.8%), *Sacoccirus* sp. (2.25%) and *Lumbroconereis impatiens* (1.6%) were the other dominant polychaetes.

Crustacea was comprised of Isopoda (14.57%), Amphipoda (4.78%), Mysidacea (3%), Decapoda (2%) and Harpacticoida (1.8%). The abundance of *Eurydice* sp. was higher during post monsoon with average values ranging from 10-487 ind m^{-2}. High abundance of *Eurydice* sp. was at stn 5HT (3832 ind m^{-2}) during post monsoon. Abundance *Cyathura* sp. (4.47%) ranged from 0-864 ind m^{-2}. High value was observed at stn 8 HT during post monsoon season. *Sphaeroma* sp. made to 3% of the total macrofaunal abundance. High abundance was observed at stn 3HT during post monsoon (2728 ind m^{-2}) and 7HT during pre monsoon (1008 ind m^{-2}).

Urothoe sp. (3.5 %) was the most dominant Amphiod. Abundance of this species was high during pre monsoon (4.5%) and monsoon season (4.73%) and showed a decline in post monsoon (2.5%). *Gastrosaccus* sp. was recorded in very high abundance, particularly at snt 5LT (2784 ind m^{-2}) during monsoon and contributed to 14% of the total macrofaunal abundance. Nemertea (3.7%) and Nematoda (1.2%) were also recorded but in low abundance.

The seasonal abundance was subjected to Bray-Curtis cluster analysis and MDS ordination. The data based on the average abundance exhibited two clusters at 50% similarity (Fig 7.6a). Stn 1,3,4,5,7,8 and 10 formed the major cluster at 63% similarity. The species which contributed to the high similarity were *Donax cuneatus* (7.5%). *Eurydice* sp. (6.9%) and *Mediomastus* sp. (6%). Stn 2 and 9 clustered at 59.9% similarity and the species responsible for the similarity was *N. cirratulus* (13 %), *Cyathura* sp. (12 %), *U.vestiarium* (12 %) and Nemertea (11 %).

The cluster analysis was later carried out for each season to detect seasonal variation in the macrofauna, if any. In pre monsoon, three clusters were detected at 50% significance. Stn 1 and 4 clustered at 76% similarity. SIMPER showed that *Donax cuneatus* (27 %), *Eurydice* sp. (26.53%) and *Sphaeroma* sp. (11%) contributed to the similarity. The second cluster was formed by Stn 7,8,9 and 10 with 56% similarity. *Cyathura* sp. (12 %), *Donax cuneatus* (10.7%) and *S. marsupialis* (10.6%) contributed to the similarity. Stn 2 and 6 formed the third cluster with 53% similarity. *S. marsupialis* (29%), *Levinsenia* sp.(27%) and *N. cirratulus* (22%) and *Urothoe* sp. (22%) contributed to the observed similarity. During monsoon only two clusters were observed. Stn 3 and 4 with 67% similarity and stn 1 and 8 with 57% similarity (Fig. 7.6c). The species which contributed to the similarity at stn 3 and 4 were *Urothoe* sp. (22%), Nemertea (13%) and *D. cuneatus* (12%). *U. vestiarium* (23%), *S. marsupialis* (16%), Nemertea (14%) and *Urothoe* sp. (12.5%) were the species which contributed to the similarity in stn 1 and 8. In the post monsoon, two clusters were observed (Fig 7.6d). Stn 2 an 9 clustered at 67% and was dominated by *Cyathura* sp. (14%), Nemertea (13%) and Nematoda (13%). The second group consisted by stns 1-5, 7-8 and 10 at 56% similarity. *Mediomastus* sp. (9%) was the most dominant species followed by Nemertea (8%), *N cirratulus* (7%), *D. cuneatus* (7%).

The average faunal biomass was 53.67 g m^{-2} during monsoon and 119.8 g m^{-2} post monsoon. High biomass was observed at the stations located in southern and north (Fig. 7.7) zone. The *U. vestiarium* contributed to 12- 100% of the total macrofaunal abundance. Macrofaunal biomass showed significant variation between the tide ($p<0.1$) and seasons ($p<0.005$).

7.3.3.2 Macrobenthic species diversity

The macrofaunal community was represented by 56 taxa. Polychaete dominated in terms of number of species (41% of total identified taxa) followed by Bivalvia and Amphipoda (11% each). Species number was high during post monsoon (52 taxa) and minimum during premonsoon (25 taxa). Stn 1 (34 taxa) and stn 10 (37 taxa) had high species number. ANOVA and Tukey's post hoc test detected significant temporal ($p<0.0001$), spatial ($p<0.001$) and tidal variation ($p<0.01$). The average species richness was high at stn 10 (7.7) and low at stn 6 (3.8). Seasonally, species richness ranged from 0.68 (pre monsoon) to 1.39 (post monsoon). Stations in the central (stn 3 and 4) and southern (stn 8 and 10) area had higher values throughout the study period. Species richness showed significant variation between tide ($p<0.01$) and seasons ($p<0.05$). In general the evenness was low in the area (0.59) and lowest value of 0.54 was during post monsoon, whereas the highest value was during monsoon (0.64; Fig. 7.8). It showed significant temporal ($p<0.0001$), spatial ($p<0.001$) and tidal variation ($p<0.01$). The lower evenness was at stn 1 and 10. Shannon-Wiener diversity indices (*H'*) ranged from 0.93 to 1.3 during monsoon and post monsoon, respectively. The values were low at stn 2 and high at stn 1 and 10. The diversity varied significantly across the tide level ($p<0.01$).

7.3.4 Macrobenthic Zonation

The faunal abundance data showed two broad biological zones: 1) the upper zone, dominated by crustacean and bivalves and the lower zone dominated by gastropods and polychaetes. As shown in figure 7.9-7.12 there was noticeable seasonal variation in all the three transect. The cluster analysis of species abundance also confirmed two biological zones. Even though, the abundance of individual species varied seasonally, the upper tidal zone in all the three transect was a crustacean-bivalve zone. The species present in this zone were *Eurydice* sp., *Cyathura* sp., *Sphaeroma* sp and *Donax* spp. The lower tidal zone was very variable as the dominance of species kept changing seasonally. The lower zone of the north and south transect was completely dominated by *U. vestiarium* and hence termed as "Umbonium zone". The distinctive species in the lower zone of the central transect was *Mediomastus* sp (Fig 7.9).

On the other hand, the seasonal zonation pattern was unclear. In the northern transect, *Cyathura* sp. and *Urothoe* sp. were the dominant during pre monsoon and monsoon (Fig. 7.10). During the post monsoon *Urothoe* sp. was replaced by *Donax* sp. The lower zone was exclusively dominated by *U. vestiarium* during all the three season.

The central transect showed two biological zones throughout the study period (Fig. 7.11). The upper zone occupied by an Isopod (*Eurydice* sp.) zone and the lower zone was represented by polychaetes (*Mediomastus* sp). The upper zone during monsoon and post monsoon was represented by *Eurydice* sp. The lower zone was represented by *Donax* spp. and *Mediomastus* sp. during post monsoon. A very high abundance of the mysid, *Gastrosacccus* sp. was observed at the low tide region (6544 ind m^{-2}) during monsoon season.

Compared to the northern and central transects the southern transect was more stable in its zonation as two biological zones were seen in all the three season. The upper zone was occupied by Isopods and *Cyathura* sp. was the dominant species. *Donax* spp. was observed during monsoon and post monsoon season. The low tide was occupied by *Umbonium*.

Analysis of distribution of the dominant species also revealed temporal variability. The abundance of *U. vestiarium* varied markedly across the beach and kept fluctuating vertically. This gastropod species was found in very low abundance or absent in the low tide during post monsoon. During pre monsoon, the low tide had high abundance of *U. vestiarium* (3232-7216 ind m^{-2}). *Donax* sp. also showed temporal variation in its vertical distribution. The species was dominant in the low tide during monsoon. Similarly, *Urothoe* sp. showed high abundance in the lower zone during pre monsoon and monsoon season. Polychaetes were widely distributed from the mid to low tide zone and hence did not show a clear distributional pattern.

The BIOENV detected a weak correlation with the environmental parameters and biological parameters ($\rho = 0.17$). Chl a showed the highest correlation ($\rho = 0.24$) with biological parameters.

7.4 Discussion

7.4.1 Environmental Characteristics

The sandy beach at Kalbadevi Bay showed variation in sediment texture. The dominance of well sorted fine sand was evident in the stations towards north and south end of the beach. The percent of coarse sand was more in the central transect, however variation was not significant. Further, sediment texture varied seasonally and the variation was pronounced in the central stations with sediment texture varying from very coarse sand to fine sand. This is due to the beach morphology as the middle transects had gradual slope from backshore to mid shore zones and further it slopes down with steep gradient upto low tide level (Ganeshan ?004). Jaramillo et al (1993) studying the intertidal zonation patterns of macrofauna in south-central Chile found a similar result with station with steep slope had coarser sand and finest sands were recorded in stations having flattest slope. The slope and particle size varies with the degree of exposure to wave action (Defeo and McLachlan 2005). This shows that the central zone of Kalbadevi Bay is subjected to higher wave actions. Therefore the stations in the center are subjected to more physical stress, high turbulence and strong currents compared to the northern and southern sites. The degree of exposure of a beach to wave action largely determines particle size, sorting and beach gradient. In the present study, sand size showed significant variation across the tidal level ($p<0.01$).

7.4.2 Population dynamics of *U. vestiarium*

U. vestiarium exists in a wide variety of colours and eleven colour patterns were observed in the present study (Table 7.1). The white (colour type 3), brown (colour type 6) and reddish brown (colour type 8) were the most widely available. The very dark colour group (4) and the brightly colourful type (10) were found in the least numbers. The dark colours in the intertidal organism are at disadvantage, since they quickly get heated and dried in sunlight (Etter 1988) and could be the possible reason for fewer dark colour types in the present collection. Predation can also markedly affect colour polymorphism in gastropods (Hughes and Mather 1986). In the present study, the area had large population of seagulls (*Larus ridibundus* and *L. brunnicephalus*). Even though, it is not known if these birds actually feed on the *U. vestiarium* population, however, they were seen in high abundance (Fig. 7.13A), possibly waiting for the *U. vestiarium* population to get exposed during low tide. The other predator of the gastropod was the starfish *Astropecten* sp. Examination of starfish revealed presence of 3-4 *U. vestiarium* in an individual. However, the low abundance of starfish (1-2 ind. $50m^2$) at Kalbadevi beach did not advocate for any predatory pressure as possible regulatory factor for polymorphism in *U. vestiarium.* Nevertheless, shell colour polymorphism is a characteristic feature of many marine and terrestrial gastropod species including *U. vestiarium* (e.g. Raffaelli 1982; Cain 1988; Rehfeld 1997).

A number of studies have been carried out to determine the factors that cause colouration in gastropod shells. In many cases, variation in shell colour was related to environmental gradients such as climate (Cowie 1990; Chang and Emlen 1993; Honek 1993), wave exposure (Etter 1988) to temperature (Kavaliers 1989), salinity (Sokolova et al. 1997; Sergievsky 1995; Sokolova and Berger 2000), metabolic rates (Steigen 1979) and fecundity (Wolda 1967). Such variation has proved to be stable and repetitive through time and space (Cain 1971; Goodhart 1973; Murray and Clarke 1978). In gastropods, shell colour may have three functions: communication, crypsis and thermoregulation (Endler 1978). For these functions, it is the shell coloration itself which is selectively important. Further, many gastropods have demonstrated a direct genetic control of shell colouration (Kozimsky et al. 1995; Ekendahl and Johannesson 1997). In the present study, the colour polymorphism in *U. vestiarium* appears to be genetical. Of all the eleven colour patterns, eight of the colour types were common, while other three occurred in small numbers and did not have very clear pattern. Further, the black, white, pink and olive greens were common and the others were a combination of these colours. Since the gametes of these gastropods are released in water, which will definitely facilitate all types of recombination possible (Rajagopal 1983). Therefore, experiments with isolated colour types may help to resolve the cause of polymorphism in *U. vestiarium.*

However, it remains to be seen whether *U. vestiarium* populations in other regions within its global range, adhere to the same colour patterning, or display additional colours and patterns. If the shell colour does indeed depend on a combination of the genetics of the animals and their environmental conditions, then there is a possibility that the colours of *U. vestiarium* specimens around the world vary depending upon the environment.

Globally the species is distributed in the Indo-West Pacific region from East Africa to eastern Indonesia; north to the Philippines and south to northern Queensland (Fig 7.13B). The species completely dominates the macrofaunal abundance and biomass of the area it is found (Berry, 1986, 1987; Ong and Krishnan, 1995). The distribution of *U. vestiarium* at Kalbadevi was restricted only to the southern and northern transects. One of the reasons why *U. vestiarium* was scattered over such great distances, could be the species preference to finer grain size. *U. vestiarium* is known to occupy neither too fine nor too coarse sandy shores (Kalyanasundaram et al. 1972). Additionally, they avoid mixed sand with mud or affected by acid, detergent and certain other chemical compounds (Kalyanasundaram et al.1974). It could also be possible that the species favour beaches where wave actions are minimal or particularly intense. The southern and northern transect of the Kalbadevi beach are flatter compared to the central which had slope which in turn affect the sediment texture. Therefore, it is possible that *U. vestiarium* reaches its greatest abundance on clean beaches with moderate wave energy. The fastidious habitat selection of the species probably accounts for its sporadic distribution on a global scale. *U. vestiarium* contributed to 34- 56% of the total macrobenthic abundance at Kalbadevi beach. Further, the abundance in the southern station was higher than in the north. Thus, a considerable difference exists between the abundance of *U. vestiarium* in the two regions and it is likely that this difference is accompanied by a difference in the level of competition among the individuals. *U. vestiarium* completely dominated the intertidal macrobenthos (Berry 1987). Their presence severely affects species diversity. A few polychaetes and predators that feed on *U. vestiarium*, such as natacid gastropods and starfish were practically the only other species known to survive in the vicinity (Berry 1987). Following the erosion of *U. vestiarium* dominated sand flat in Telok Aling beach, Penang, the macrobenthic community changed from consisting almost entirely of *U. vestiarium* to consisting largely of polychaetes and bivalves. Subsequently, the species richness increased substantially (Ong and Krishnan 1995). Starfish (*Astropecten* sp.) seemed to be the only predator of *U. vestiarium* at Kalbadevi beach.

The gastropod size, like the abundance showed variation between the two populations. The specimens in the north were found to be larger than the southern ones. Samples from the south did not exceed 12 mm in diameter. The smallest individuals in the south were observed during August-September. Likewise, difference was observed in the shell size in the north samples. The smallest individuals in the north were observed during April '05 and September '05. During August '04, mean size of gastropod in the south ranged from 6.5-11.9mm. Almost 45% of the population was in the 8-10mm size class. However, in the north, 88% of the population was in the 11-13mm size class. *U. vestiarium* was completely absent during early monsoon (June) at both transects. The monsoon changes lead to increased wave action resulting in disturbance and dispersion of *Umbonium* and redistribution in the subtidal region (Berry and Othman 1983). Further, the drop in salinity can cause mortality or changes in salinity triggers reproduction in the *Umbonium* population (Broom 1982). Berry (1987) reported a similar reduction of *U. vestiarium* during the monsoon along the Malayasian coast.

The *Umbonium* population during the late monsoon (August) was represented by juveniles suggesting that recruitment by larval settlement. The climate conditions are calmer during this period and along with reduced wave action favoured the settlement and establishment of the *Umbonium* population. Thus, it can be concluded that recruitment of *U. vestiarium* at Kalbadevi beach occurred during the monsoon period (June-September) as the smallest size class was also seen during September '05 at both the sites. The recruitment seen in April'05 along north transect may be occasional case of delayed spawning, since 84% the population during May 2004 comprised of 10-11 and 11-12mm size class.

According to Berry (1987), the reproductive period of *U. vestiarium* is from March-June for the Malaysian population. However, Berry (1987) has suggested that *U. vestiarium* populations around the world are not genetically identical and thus, Indian and Malaysian populations could have varying spawning periods. Most molluscan species undergo annual spawning cycles with a single spawning event each year (Worthington and Andrew 1997; Ward and Davies 2002). However, species may show variation in spawning periodicity across its geographic range (Parry 1982; Fletcher 1987). Most studies on turbinids conclude that they are annual spawners (Toshiaki 1993; Hideki et al. 1995; Foster et al. 1999). However, several trochid species such as *Umbonium costatum* from Japan (Noda et al. 1995) and *Astrea undòsa* from Mexico (Belmar- Perez et al. 1993) are capable of spawning twice a year. Underwood (1974) also found incomplete spawning for a number of archaeogastropods in New South Wales, particularly the smaller congener *Turbo undulatus* and the limpet *Patella peroni.*

It can be concluded that the differences observed in the population of north and south site probably was due to some biotic and abiotic differences between the two habitats. The differences between the populations at the two sites probably stemmed from the feeding competition among the gastropods. The high gastrapod populations in the south can generate stiff feeding competition among the gastropods resulting in the smaller size of individuals. Further, the recruitment of *U. vestiarium* like other tropical species occured during the monsoon season.

7.4.2 Spatio-Temporal variability of macrobenthic community

The macrobenthic abundance at Kalbadevi beach showed a significant seasonal variation. The community was low during the monsoon season and high abundance was observed during post monsoon season. The changes observed in the community were related to the dominant species of the area. Macrofaunal abundance was low during monsoon as the communities are known to respond negatively to monsoonal rains. The impact of monsoon has been reported to cause defaunation or reduction of species due to mortality, removal by erosion or mortality by reduced salinity (Ansell 1972; Ansell et al. 1977; McLuksy et al. 1978). Severe beach erosion takes place during the monsoon, and only species capable of migrating persist (Alongi 1990). Erosion and accretion processes displace and bury infauna in the more inclined, high intertidal sands (Achuthankutty, 1976; Harkantra and Parulekar, 1985; Ingole and Parulekar 1998). Drop in salinity triggers spawning which is responsible for increased reproductive out put of species with planktonic larval stage (Broom 1982). Another faunal response to low salinity during monsoon is mortality (Goodbody 1961). Dobbs and Vozarik (1983) did not observe any difference in abundance of pre- and post storm collection, but reported large post storm increase in the number of infaunal species individuals in the water column. They suggested water turbulence suspended benthic fauna and helped in the wide spread dispersal of both larvae and adults. In regions where erosion is not seen during monsoon, faunal responses are species specific and total community response depends upon the frequency and intensity of climatic disturbances and the time of the year (Alongi 1990).

The polychaete abundance was low during monsoon whereas in post monsoon it was the most dominant group and was comprised of juvenile population. According to Nair (1978) change in sediment texture during monsoon has a direct bearing on the distribution of certain faunal groups, especially polychaetes that recover with return of stable conditions. Crustaceans also showed decline in abundance during monsoon except for mysid which showed unusually high dominance. The Mysid, *Gastrosaccus* sp. made to 14% of the total macrofaunal abundance. Therefore, the temporal variations seen in the macrofaunal community are related with the changes caused by recruitment, mortality and production (Ismail 1990; Jaramillo et al. 1993; Bamber 1993; Santos 1994;).

Species diversity, abundance and dominance of sandy beach communities are often associated with environmental conditions such as sediment particle size, organic content, beach slope and food in surf water (Defeo and McLachlan 2005). Polychaetes and gastropods were dominant towards the northern and southern stations, whereas crustaceans were more dominant in the central stations. Generally, as grain size increases from finer to coarser texture and with the increase in wave exposure, crustaceans dominate towards coarser and more exposed areas (Junoy and Viéitez 1989; McLachlan 1983; Fresi et al. 1983). While polychaetes and molluscs increase towards the other side of that gradient (McLachlan et al. 1981; Dexter 1984). Omena et al (2000) studied the relationship between sedimentary dynamics and spatial distribution of spionid polychaeta along the intertidal region of Dois Rios beach (Ilha Grande, Southeast Brazil) and suggested that distribution pattern of intertidal polychaetes was in agreement with fine sediments distribution throughout the beach. McLachlan (1996) reported a similar finding in the Elizabeth bay, Namibia. However, though the polychaete showed dominance towards the finer sand, the correlation of grain size and macrofaunal group abundance did not show significant correlation. Similarly, crustacean abundance showed a weak positive correlation with grain size. This was because many crustaceans did not show response to sediment type. The abundance of cirolanidae isopod was greater in the central transect (area with coarse sand), whereas Anthuridae isopods and Amphipoda dominated towards the north and south stations which had fine sand. This may be the reason for the weak correlation between the crustacean abundance and sediment texture. Therefore, morphodynamics of sediment is not always the critical feature for determine the distribution of macrobenthic community and agrees with the study of (Jaramillo et al. 1990).

Overall, macrofaunal abundance was high at the northern and southern transect. The high abundance of macrofauna was due to high abundance of the gastropod *U. vestiarium* at these transects. The high abundance of macrofauna may be due to the availability of food. Nutrients were highest at southern transect followed by, northern transect and central transect, respectively (Anon 2004b). Are and Kalbadevi creek drains into the area in the north and south, respectively. These creeks have rich fringing mangrove vegetation, and decomposition and litter fall could contribute to the increased nutrient levels (Dham et al. 2002). Similarly, the values for sediment as well as surf water chl a (Anon 2004b) and sediment OC were high towards south and north. The high input of nutrients from the creeks in the south and north must have resulted in high primary productivity. This could certainly support the rich benthic community. Sandy beaches are known to have functional ecological linkages with adjacent ecosystems such as sand dunes, the surf zone, estuaries and coastal lagoons (Short and Hesp 1982). Increased river flow also increase nutrient and carbon transport from rivers into the coastal zone (Langland et al. 2001; Justic et al. 2003), contributing to a variety of biological and biogeochemical responses such as increased primary production and benthic nutrient recycling (Boynton and Kemp 2000). Further in the southern transect large quantities of drifted seaweeds were observed (Anon 2004b). The drifted seaweeds can also add to beach energetic and biomass. The fluctuation in the macrofaunal production was related to environmental stress and availability of food (Nair 1978; Defeo and McLachlan 2005). Therefore the greater abundance and biomass observed at the north and south of the study are can be attributed to food availability, due to the increased nutrient and carbon flow from the adjacent creeks. As also evident form the BIOENV which gave the best correlation with chl a, though not statistically significant.

In sandy beaches the macrobenthos are represented by different phyla, but crustaceans, mollusks and polychaetes dominates (Brown and McLachlan 1990). In Kalbadevi, although gastropod dominated in terms of abundance and biomass, Polychaeta was the more diverse group (22 species) which is observed in many of the beaches world-wide (Amaral et al. 1995; Brown and McLachlan, 1990). The high tide recorded fewer polychaete species than the mid and low tide zone, agreeing with various authors (Jaramillo 1996; Barros et al. 2001; Rizzo and Amaral 2001). The dominant polychaete species showed temporal variation and the community was dominated by *N. cirratulus* and *S. marsupialis* during pre monsoon and monsoon. In the post monsoon, the polychaete population was dominated by the capitellid, *Mediomastus* sp. The spionids are the dominant species in many sandy beaches (Defeo et al. 1992; Borzone et al. 1996).

Due to their small size, harpacticoids are seldom reported in sandy beach macrofauna. However, the large sized (>0.5mm) species were recorded in high abundance at mid-tide level of stn 6. Harkantra and Parulekar (1985) and Dexter (1996) also made a similar observation respectively at Siridao beach, Goa and at Phuket Island, Thailand.

The results of the present study indicate that macrofaunal communities of Kalbadevi was generally species rich than reported for many of the beaches along the west coast of India. Ansell et al (1972) reported 5 species in Shertalii and 3 species in Cochin. Eleven species were recorded from Sancolae (Achuthankutty 1976) and 8 from Baina (Achuthankutty et al. 1978). Harkantra and Parulekar (1985) reported 35 species from estuarine sandy beach of Siridao. Ingole (2003) recorded 49 species from Miramar beach, Goa; whereas 56 species were reported from the sandy beach of Malvan (Parulekar 1981). Compared to the other west coast beaches, notable differences were observed in the species composition. *Donax incarnatus, D. spiculum, Emerita holothuisi* were the common inhabitants of these beaches. It accounts for the major portion of the macrobenthic abundance and biomass. However, these commonly species was very low at Kalbadevi. Interestingly *U. vestiarium* was the dominant in terms of density and biomass and accounted to 90% of the macrobenthic biomass. This species has been reported from some of the above beaches but with very low abundance.

The biomass of macrofauna was variable but generally high compared to many other beaches along the west coast of India and world wide (McLachlan, 1981a; Rodil and Lastra 2004). Ansell (1972) reported biomass value ranging from 0.02-300 g m^{-2}. Achuthankutty (1978) reported biomass of 0.2-160 g m^{-2}. At Kalbadevi beach *U. vestiarium* was the dominant species in terms of biomass. McLachlan (1983) suggested that molluscs usually dominate the intertidal portions of sandy beaches in terms of biomass. The high values of biomass recorded at Kalbadevi here indicate the importance *U. vestiarium* in benthic production and ecosystem functioning.

Community structure such as total number of species and evenness showed seasonal, spatial and tidal variation. Species diversity varied across the zone. In general, the evenness and species richness was low as the community was dominated by few species. The observed fluctuation in species richness and evenness was due to the changes in the dominant species influenced by recruitment and mortality brought about by seasonal changes. This is a typical phenomenon in sandy beach ecosystem wherein species evenness and diversity are influenced by the population dynamic of numerically abundant species (Holland and Polgar 1978; Dexter 1984). After the monsoon, there was an increase in number of species, diversity and change in species composition. Grassle and Sanders (1973) observed similar changes in species diversity and concluded that unsaturation allowed more species to occupy the habitat, mainly by immigration of other species from vicinity. Recolonization of a defaunated area usually involved different species composition with opportunistic or fugitive species becoming abundant in the early stages (Johnson 1974; Arbugov 1982). Correlation analyses among species richness, versus sediment grain size, sediment organic carbon and chlorophyll *a* did not show significant relationship.

7.4.3 Macrobenthic Zonation

There are a number of schemes for classification of the intertidal fauna of sandy habitat. The zonation scheme most widely used for sandy beaches is that of Dahl (1952) and Salvat (1964). The former scheme was based on biological zones and the latter on physical characteristics of the beaches. McLachlan et al (1981) have devised a tripartite zonation scheme for South African sandy shores. The boundaries and indicator species of these three zones viz. the littoral fringe; eulittoral zone and sublittoral fringe have also been identified. They suggested that mysid, *Gastrosaccus sp.* could be considered as an indicator species of the lower zone as they have been recorded universally. However, biological zones are valid, if they include the center of gravity of at least one characteristic species, and should be perceptible without recourse to sophisticated statistical techniques (McLachlan and Jaramillo 1995). Nonetheless, the biological zones in sandy beaches, however, are not as clearly defined, as a consequence of the dynamic environment.

In the present study, it was difficult to establish a clear zonation pattern for the intertidal sandy beach of Kalbadevi for several reasons. Firstly, the macrofaunal community showed variation in all the three transects. Second, many of the species showed overlapping in distribution, and third, the community showed significant seasonal variation. Based on the average seasonal data the area can be divided into two broad biological zones. The upper zone in all the three transects was dominated by Isopods. *Cyathura* sp. in the north and south transects, whereas the central transect was represented by *Eurydice* sp. The lower zone in the north and south was dominated by gastropod *U. vestiarium*. Central transect was dominated by *Mediomastus* sp. Generally, the upper zone was narrow and better defined compared to the lower zone. The upper zone was narrow and clearest compared to the wider lower zone because the concave slope of most beaches results in more gradual horizontal changes associated with the intertidal gradient toward the lower shores (McLachlan and Jaramillo 1995). Many workers have pointed out the difficulties in establishing major biological zones of the intertidal area (Raffaelli et al. 1991; Defeo et al. 1992), and have suggested that the only applicable zonation scheme might be that of Brown and McLachlan (1990). This scheme recognizes two zones: higher shore assemblages of air-breathers, below which all species are water- breathers which agrees with the present finding.

One factor that could explain the lack of true zonation at Kalbadevi is the seasonal sampling that covered the entire beach. Most of the studies on sandy beach zoantion were based on single sampling covering as many beaches as possible (e.g McLachlan 1990; Jaramillio and Gonzalem 1991). Such sampling masks the effect of seasonal migration caused by modification of shoreline influenced by meteorological changes.

Such dynamic system produces distribution of community different from those observed in predictable environments (de Alava and Defeo 1991). Another reason for the absence of a clear zonation pattern at Kalbadevi was spatio-temporal dominance of different species in the area.

In fact, not only the occurrence, but also the distribution of the dominant species was seasonally marked. However, the variation was less in the upper zone. The term "zonation" may be inappropriate for the majority of the species present at Kalbadevi because across-shore distributional boundaries of sets of species did not coincide. Further, many species migrate tidally across the shore such that any "zones" would vary in time (Hacking 1996). Omar et al (1992) studying the community structure and intertidal zonation of the macroinfauna on Uruguay coast also showed an absence of general zonation pattern. Defeo et al (1992) concluded that no consistent patterns of zonation occurred for several beaches in Uruguay. Non-consistent patterns of zonation have also been reported by McLachlan (1990) on four dissipative beaches in North America. Mills (1969) and Hughes and Thomas (1971) observed that different distribution patterns of species were a continuum of overlapping and so, usually difficult to establish well-defined biological zone. It has been also shown that zonation patterns of the macro-in fauna changes according to beach types; i.e., the complexity of the patterns or the number of faunal belts across shore, increase from reflective to dissipative beaches (Jaramillo et al. 1993; McLachlan and Jaramillo 1995).

7.5 Conclusion

The *U. vestiarium* showed a scattered distribution in the area and was restricted to the northern and southern end of the beach. The polymorphisms observed in the gastropod seem to be genetically which requires detail study to conform the same. The macrobenthic community of the area was dominated by gastropod and polychaete in terms of abundance. Polychaete was the most diverse group. The macrofaunal did not show clear zonation due the spatio-temporal variability in the community.

Natural variability occurs in ecosystem due to intrinsic process (competition, predation, recruitment) and natural disturbance (storm and flood). Any disturbance in the environment can be determined if it brings about changes in the system different from the natural changes. Therefore, it is important to understand the natural variability pattern and the factors influencing this variability for the management of this potential placer mineral mining site. The present study will therefore form at least part of the basis of our understanding and management of this potential placer mineral mining site.

This information will contribute to the global database on macrofauna as this area has not been studied so far. It will also serve as reference information for assessment of environmental impact that would occur as a result of placer mining in future.

Table 7.1
Granulometry for the ten transect in the intertidal region of Kalbadevi Bay

	D50 (µm)	V coarse sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	V Fine Sand (%)
1HT	168.79	0.01	0.01	1.17	75.50	23.30
1MT	174.74	0.03	0.02	2.42	89.17	8.36
1LT	186.03	0.05	0.41	12.95	83.17	3.42
2HT	109.25	0.03	0.01	1.27	45.49	53.19
2MT	193.59	0.36	0.11	18.67	75.28	5.58
2LT	196.99	1.16	3.32	22.06	67.52	5.94
3HT	203.83	0.45	1.42	27.03	63.88	7.22
3MT	243.71	16.77	11.15	20.65	42.03	9.40
3LT	182.68	0.57	1.16	12.67	76.57	9.03
4HT	217.46	0.04	0.93	32.56	59.04	7.44
4MT	184.81	2.09	4.73	17.67	60.14	15.37
4LT	201.39	1.97	6.99	25.54	51.88	13.61
7HT	273.32	4.69	9.77	45.57	38.16	1.81
7MT	1394.28	69.88	5.96	9.81	11.02	3.33
7LT	268.21	14.83	9.99	29.80	39.89	5.50
8MT	161.91	6.70	6.23	10.16	40.71	36.20
8LT	173.53	1.09	1.71	8.46	69.25	19.50
9HT	70.22	0.05	0.01	1.07	9.74	89.1
9MT	168.52	0.29	0.53	4.13	69.59	25.46
9LT	172.03	0.89	2.32	7.22	68.00	21.57
10HT	123.06	0.02	0.02	0.89	48.60	50.47
10MT	187.37	3.25	6.82	16.98	58.11	14.84
10LT	192.20	1.41	5.55	18.14	66.92	7.98

Table 7.2
Shell colour pattern in *Umbonium vestiarium* and percent distribution in the North and South transect Kalbadevi beach.

Colour type	Colour/Pattern Description	North (%)	South (%)
1	White with prominent dark stripes	5	10
2	Dull pink/Greyish with pink swirls	9	9
3	White	15	13
4	Dark brown/black	4	5
5	Bright or dark pink/red	9	11
6	Olive green	14	14
7	Brown with orange tinge/orange	9	11
8	Brown with reddish tinge	15	12
9	Spiral pattern (multicoloured)	12	7
10	Spiral pattern with striped between the swirls (multicoloured)	5	5
11	Spiral (either like 10 or 9) but incomplete pattern (multicoloured)	2	2

Table 7.3
Seasonal variation in the distribution of macrofaunal species at Kalbadevi beach. (+: Present ; - : Absent)

	Pre monsoon	Monsoon	Post monsoon
Nemertea	+	+	+
Nematoda	-	-	+
Polychaeta			
Pisionidens indica	-	-	+
Pisione sp.	-	+	+
Pilargidae	-	+	+
Saccocirrus sp.	-	+	-
Phyllodoce sp.1	+	+	+
Onuphis eremita	+	+	+
Eunice sp.	-	+	+
Nereis sp.	+	+	+
Glycera alba	+	+	+
Glycera longipinnis	-	+	+
Goniada sp.	-	+	+
Lumbriconereis impatiens	+	+	+
Mediomastus sp.	+	+	+
Levinsenia sp.	+	+	+
Nerine cirratulus	+	+	+
Prionospio sp.	-	+	+
Pseudopolydora sp.	-	+	+
Polydora kempi	-	+	+
Cirratulidae	-	+	+
Scoloplos marsupialis	+	+	+
Nepthys sp.	+	+	+
Armandia lanceolata	+	+	+
Oligochaeta	+	+	+
Insecta			
Chironimidae	-	+	+
Unidentified Insecta	-	-	+
Bivalvia			
Mactra sp.	-	-	+
Donax cuneatus	+	+	+
Donax sp.2	-	+	+
Donax sp.3	-	-	+
C. scabra	-	-	+
Sunetta sp.	+	-	+
Gastropoda			
Babylonia spirata	-	-	+
U.vestiarium	+	+	+
Turitella sp.	-	+	+
Harpacticoida	+	+	+
Isopoda			
Eurydice sp.	+	+	+
Cyathura sp.	+	+	+

Contd............

Table 7.3

	Pre monsoon	Monsoon	Post monsoon
Sphaeroma sp.	+	+	+
Decapoda			
Eupagrus sp.	+	+	+
Ocypoda sp.	-	-	+
Unidentified crab	+	+	+
Emerita sp.	+	-	+
Amphipoda			
Orchestia sp.	-	+	+
Urothoe sp.	+	+	+
Synchelidium sp.1	-	-	+
Synchelidium sp.2	-	-	+
Phoxocephalus sp.	-	+	+
Monoculodes sp.	-	+	+
Cumacea	-	+	+
Mysidacea			
Gastrosaccus sp.	+	+	+

Table 7.4
Seasonal variation in % composition of macrofaunal group

	Pre monsoon	Monsoon	Post Monsoon
Nemertea	0.75	2.76	5.68
Nematoda	0.00	0.00	2.32
Polychaete	15.83	23.82	42.86
Oligochaeta	0.27	1.60	0.80
Insecta	0.00	2.68	0.54
Bivalvia	4.34	7.08	9.68
Gastropoda	55.92	34.37	11.72
Harpacticoid	0.36	5.22	1.38
Isopoda	16.49	3.43	16.73
Decapoda	1.52	0.13	3.30
Amphipoda	4.89	5.31	4.76
Cumacea	0.00	0.09	0.08
Mysidaceae	0.06	14.11	0.16

Table 7.5
Dominant Macrofaunal species during pre monsoon season, Kalbadevi beach.

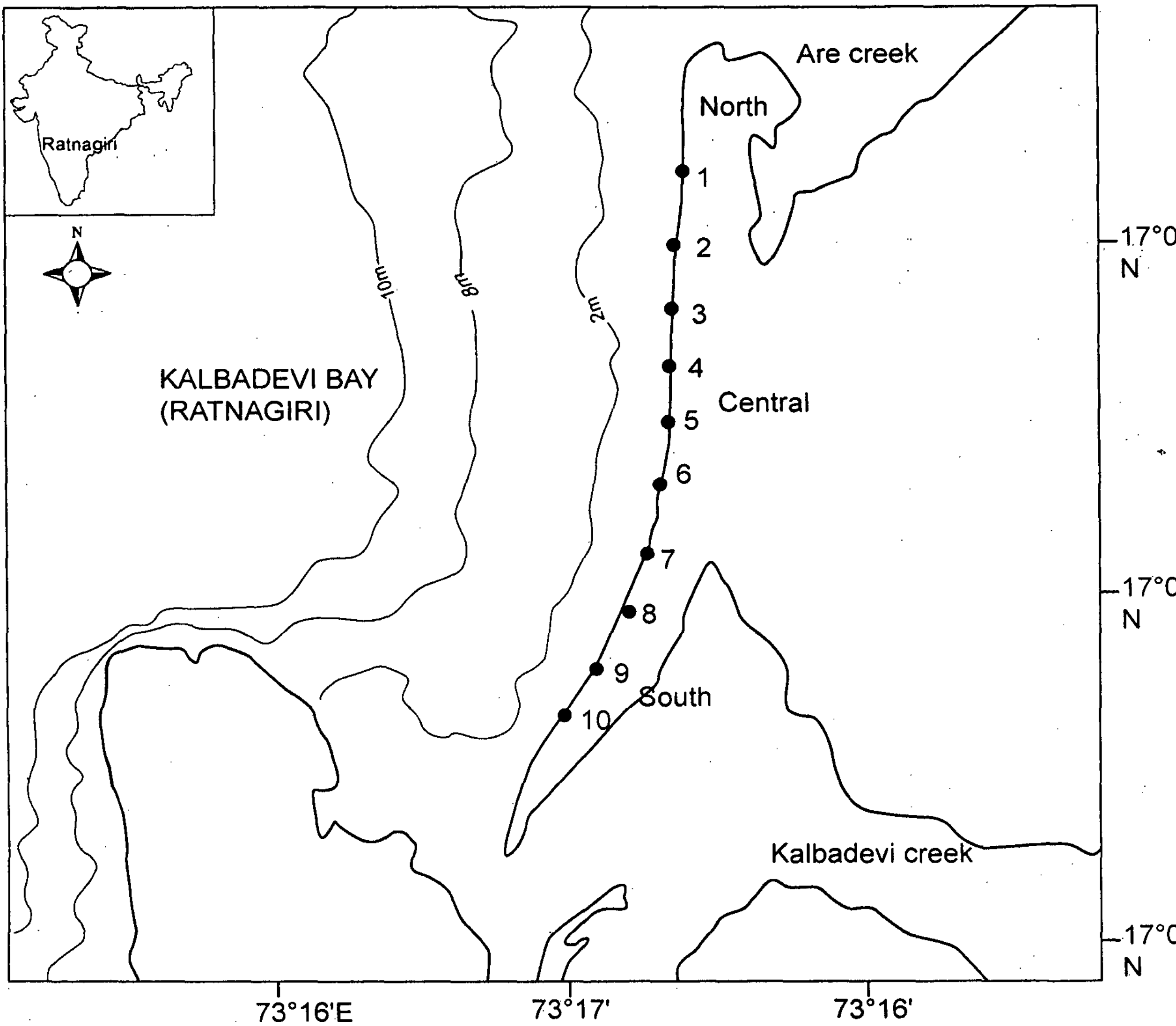
	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 8	Stn 9	Stn 10
L. impatiens	0	0	0	0	0	0	109	58.9	125
Levinsenia sp.	0	147	0	0	0	59	5.3	0	3
Nerine cirratulus	0	133	8	0	0	29	48	442	131
S. marsupialis	0	178	0	0	0	88	104	147	19
Donax cuneatus	184	0	0	165	0	0	91	29	85
U.vestiarium	0	265	0	0	0	0	0	2828	4264
Eurydice sp.	496	0	0	136	0	0	48	0	61
Cyathura sp.	200	353	0	11	11	0	429	60	144
Sphaeroma sp.	168	0	0	24	5	0	19	0.0	5
Urothoe sp.	40	206	8	16	64	29	205	60	16

Table 7.6
Dominant macrofaunal species during monsoon, Kalbadevi beach.

	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 8	Stn 9	Stn 10
Nemertea	107	44	27	21	32	29	64	0	5
Pisione sp.	0	0	0	0	0	265	0	0	0
Saccocirrus sp.	0	0	0	0	0	1208	0	0	0
Levinsenia sp.	0	0	11	0	16	0	165	265	0
Nerine cirratulus	69	0	5	0	0	0	11	0	3
S. marsupialis	149	44	27	5	0	0	117	0	3
Oligochaeta	0	44	0	0	0	147	0	0	0
Chironimidae	320	0	0	0	0	0	0	0	0
Donax cuneatus	5	0	16	59	0	0	368	177	5
U.vestiarium	3131	88	27	0	0	0	795	0	59
Harpacticoida	123	0	5	5	32	29	5	353	0
Cyathura sp.	0	44	5	11	8	0	27	177	19
Urothoe sp.	69	0	293	176	0	0	37	0	0
Gastrosaccus sp.	176	0	16	5	1416	29	0	0	43

Table 7.7
Dominant macrofaunal abundance during post monsoon, Kalbadevi beach.

	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	Stn 8	Stn 9	Stn 10
Nemertea	29	442	104	69	40	501	35	132	92
Nematoda	3	177	0	48	3	0	72	132	183
Mediomastus sp.	16	0	189	187	40	1561	792	0	1323
Levinsenia sp.	3	88	0	19	3	206	27	751	28
Nerine cirratulus	11	1679	96	69	67	177	59	88	63
S.marsupialis	3	353	3	19	11	353	21	44	33
Donax cuneatus	160	88	1360	75	488	88	5	88	7
U.vestiarium	829	0	669	0	0	0	0	177	1455
Eurydice sp.	131	0	869	67	1435	0	8	0	0
Cyathura sp.	0	177	75	3	0	0	83	442	13
Sphaeroma sp.	37	0	915	0	5	29	0	0	0
Emerita sp.	8	0	3	0	56	589	3	0	0
Urothoe sp.	35	442	75	11	5	0	29	88	0



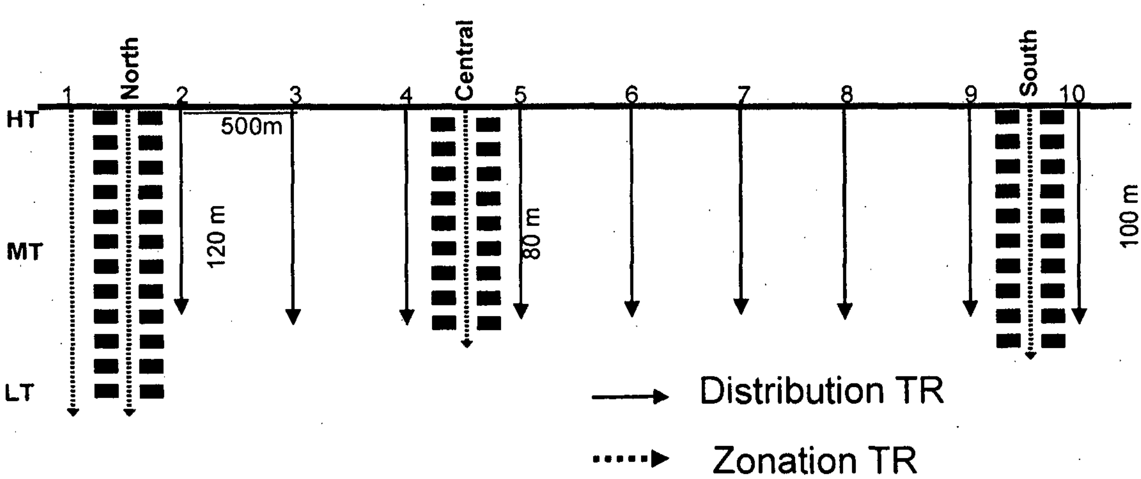


Fig 7.1 Map showing location of the transects in the intertidal zone of Kalbad

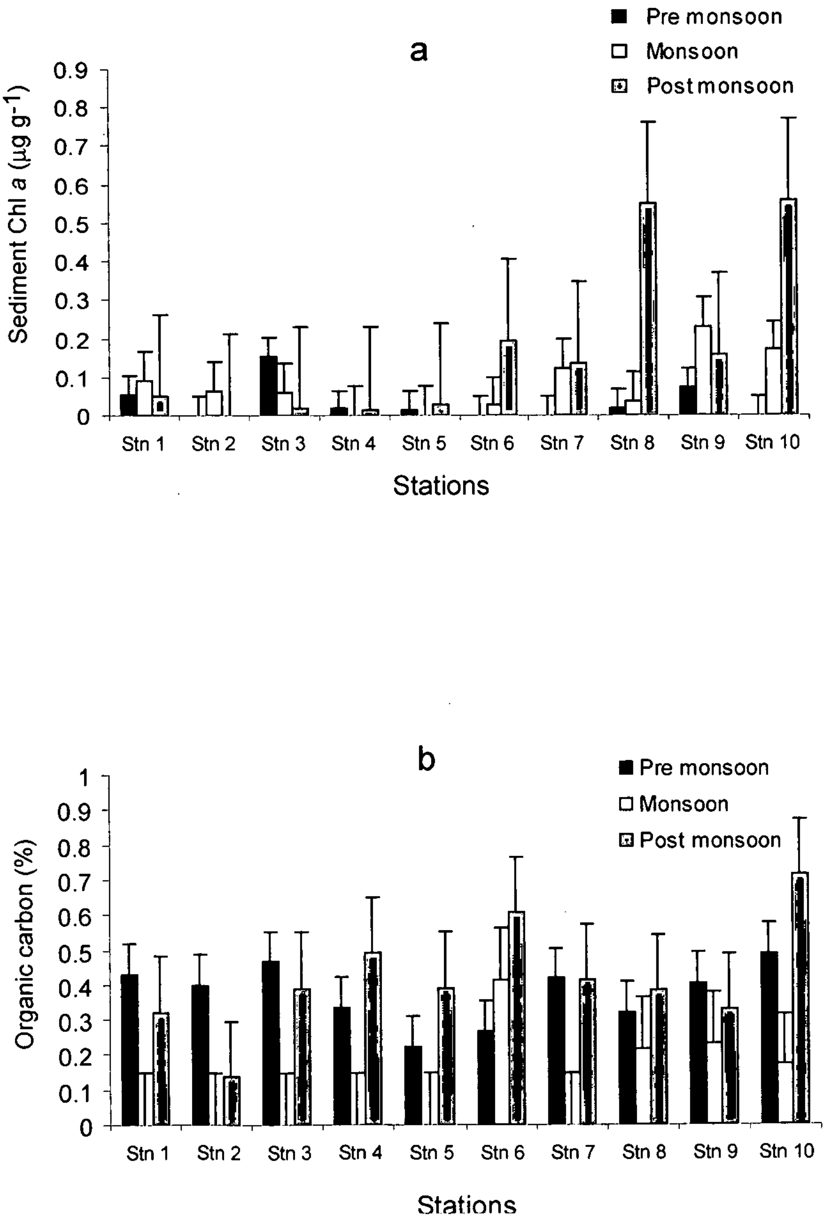


Fig 7.2 Spatio-Temporal variation (±SD) of chl *a* (a) and OC (b) in the study area

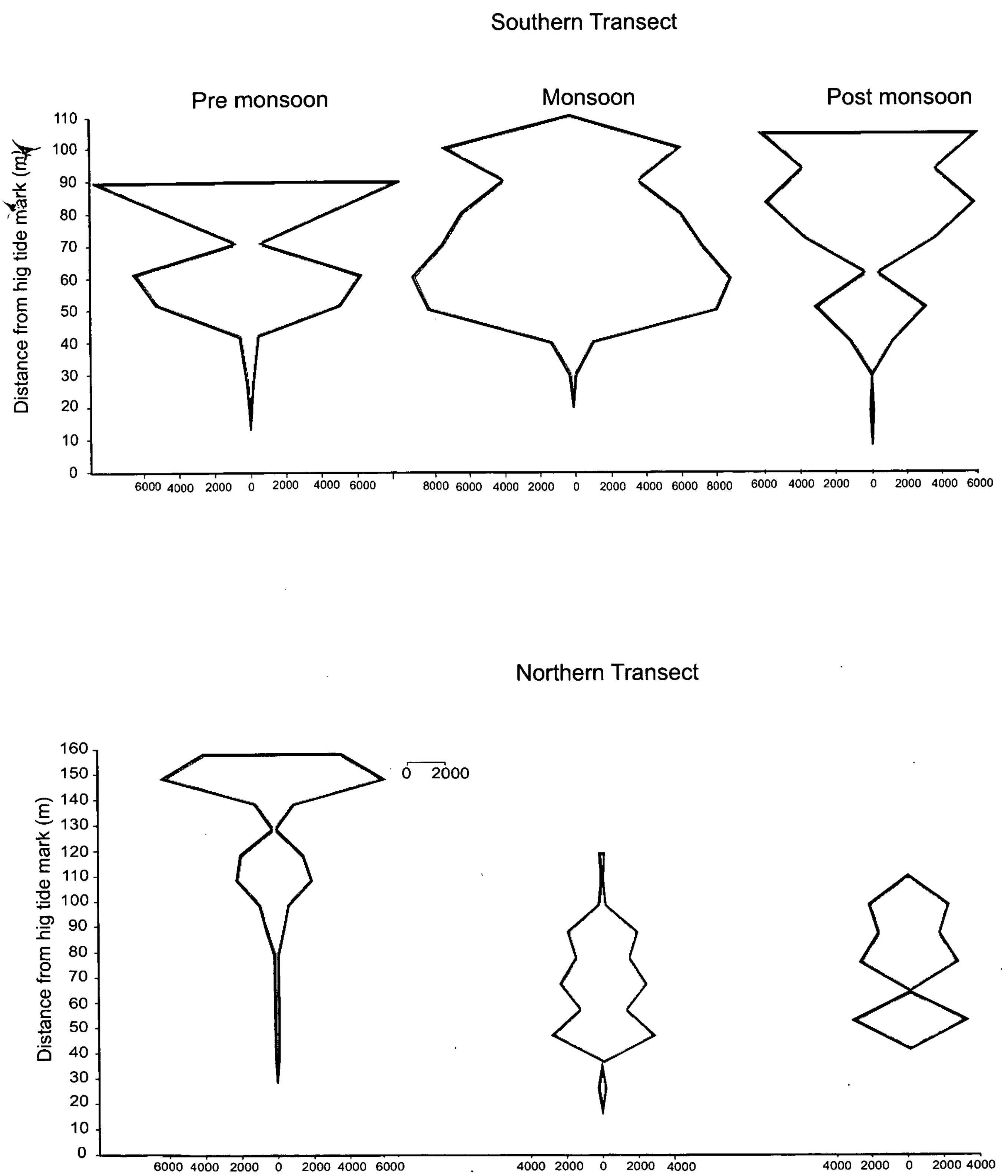
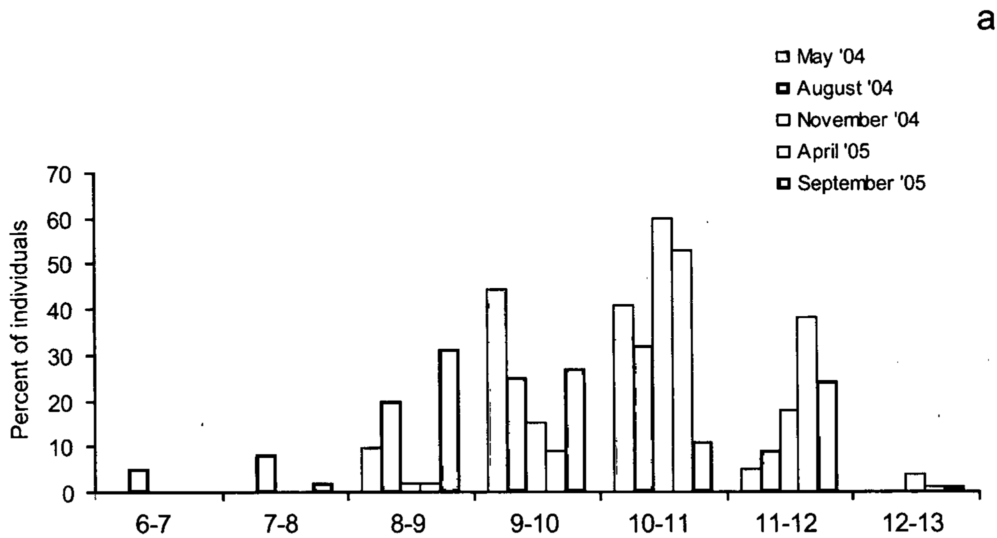


Fig 7.3: Kite diagram representing seasonal distribution of *U. vestiarium* in the southern and Northern transect.



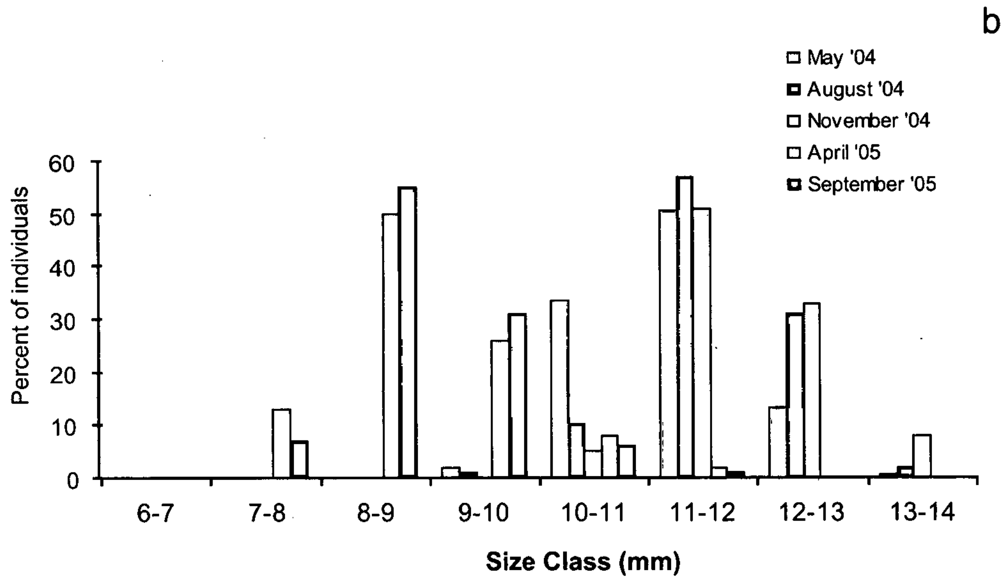


Fig 7.4 Distribution of different size class of *U. vestiarium* in the southern (a) and northern transect (b).

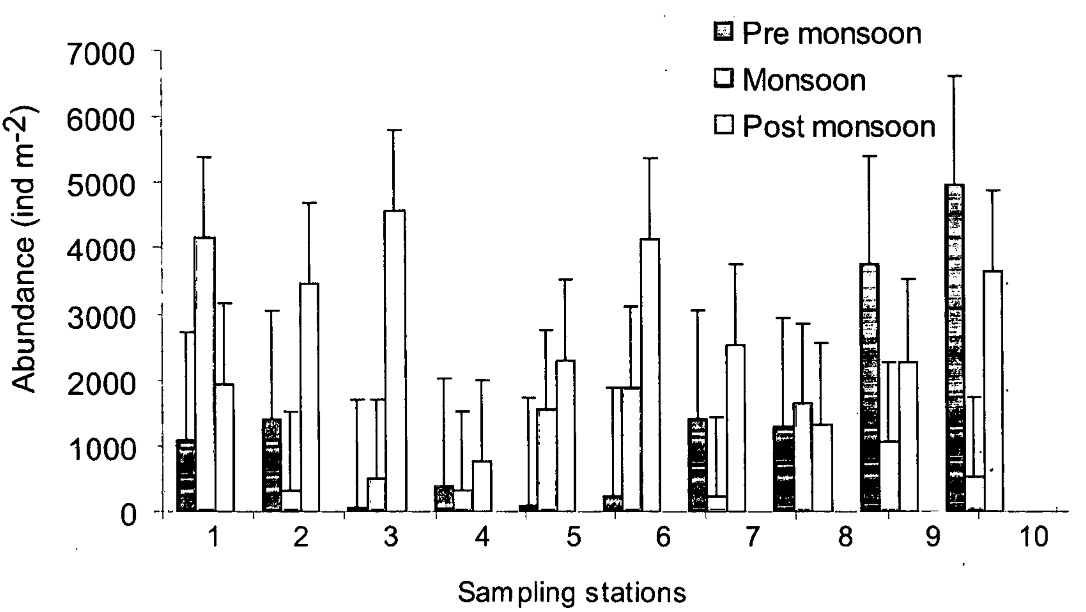


Fig 7.5 Spatio-temporal variation (±SD) of macrofaunal abundance the study area

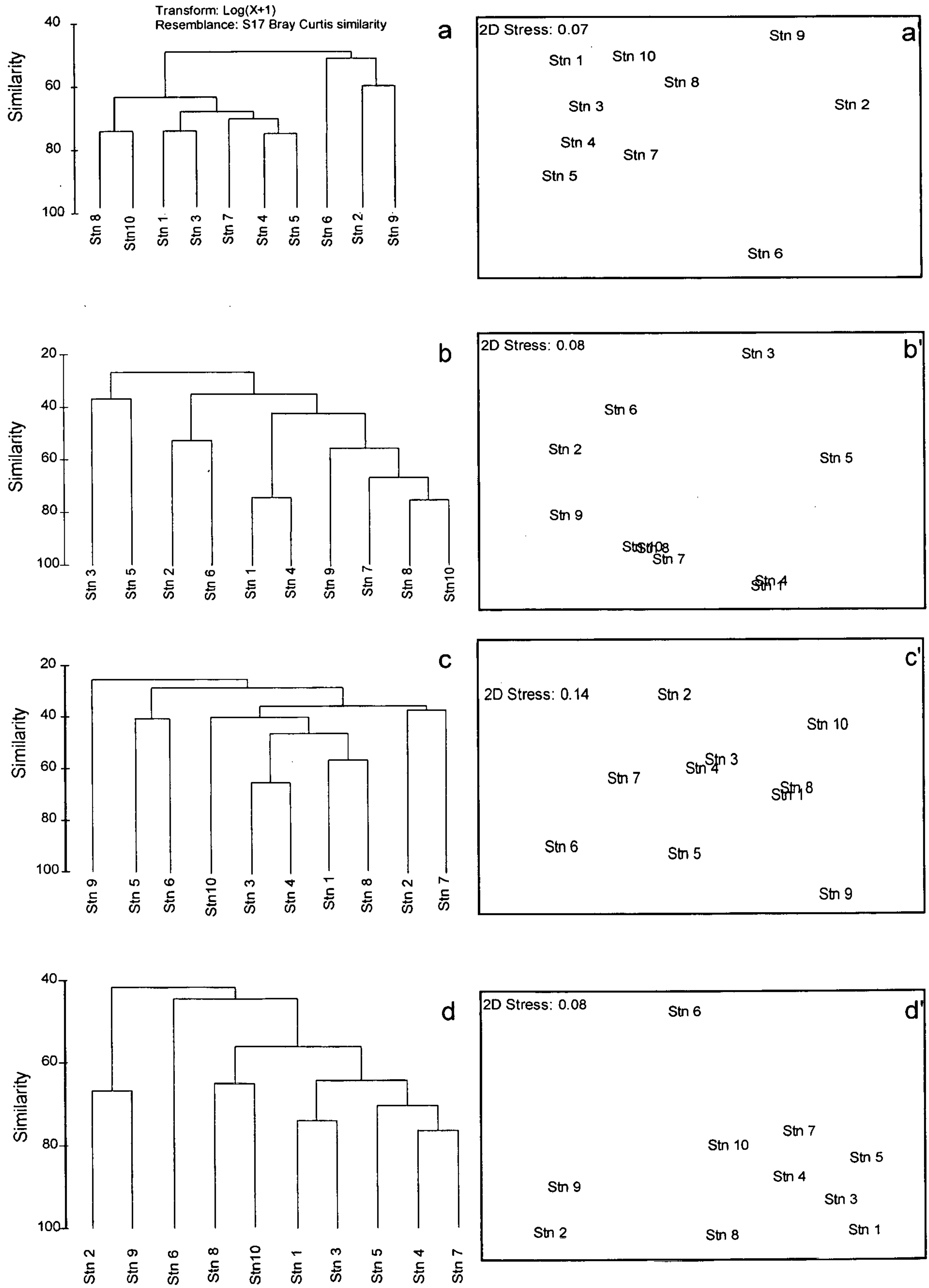


Fig 7.6: Bray-Curtis cluster and MDS based on macrofaunal abundance for average data (a) premonsoon (b monsoon(c), post monsoon (d).

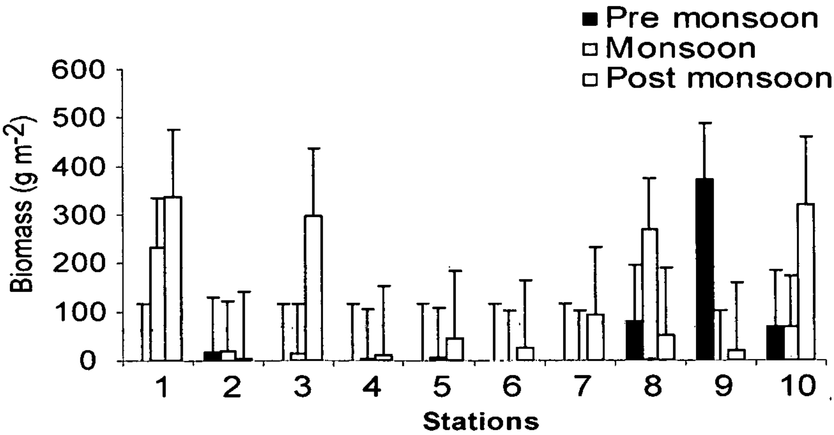


Fig 7.7 Spatio-temporal variation of macrofaunal biomass in the study area

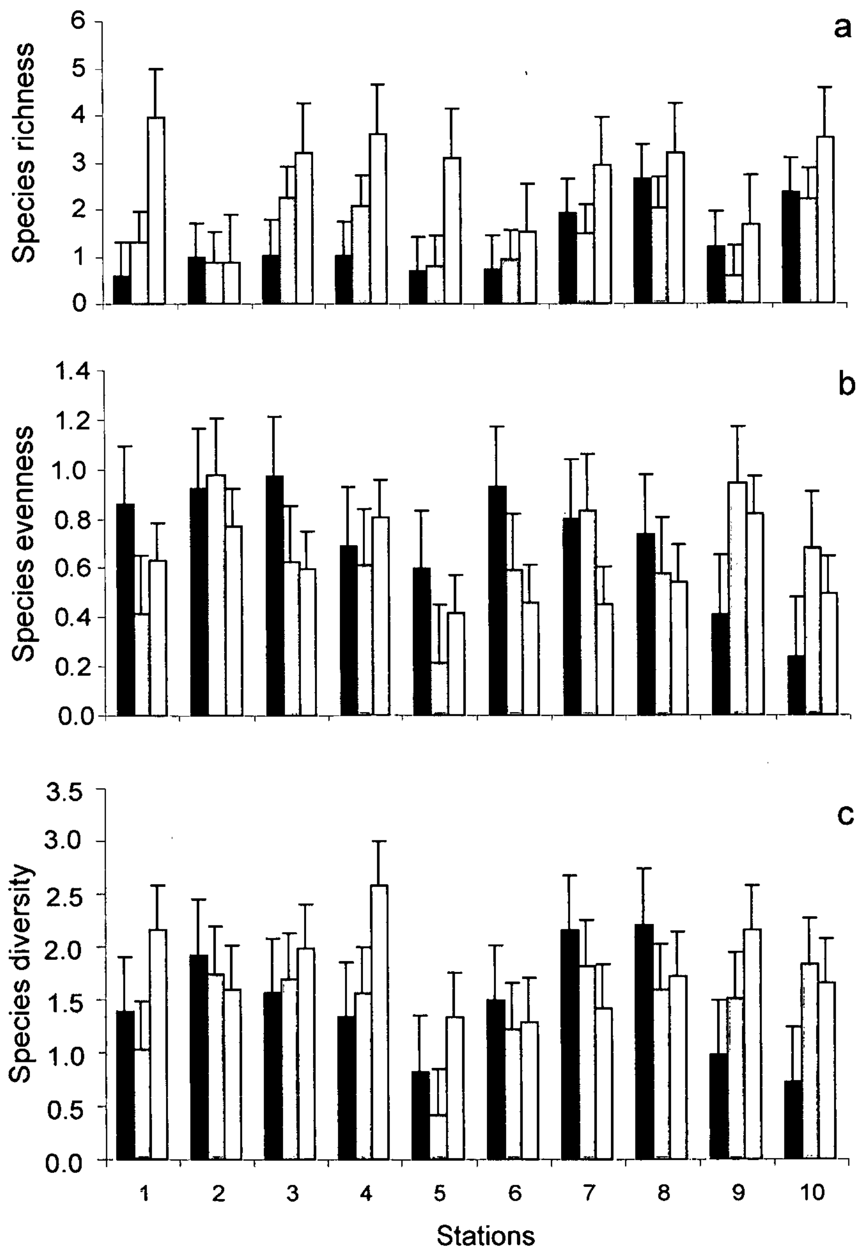


Fig 7.8 Spatio-Temporal variation of macrofaunal species richness(a) species evenness (b) and species diversity(c).

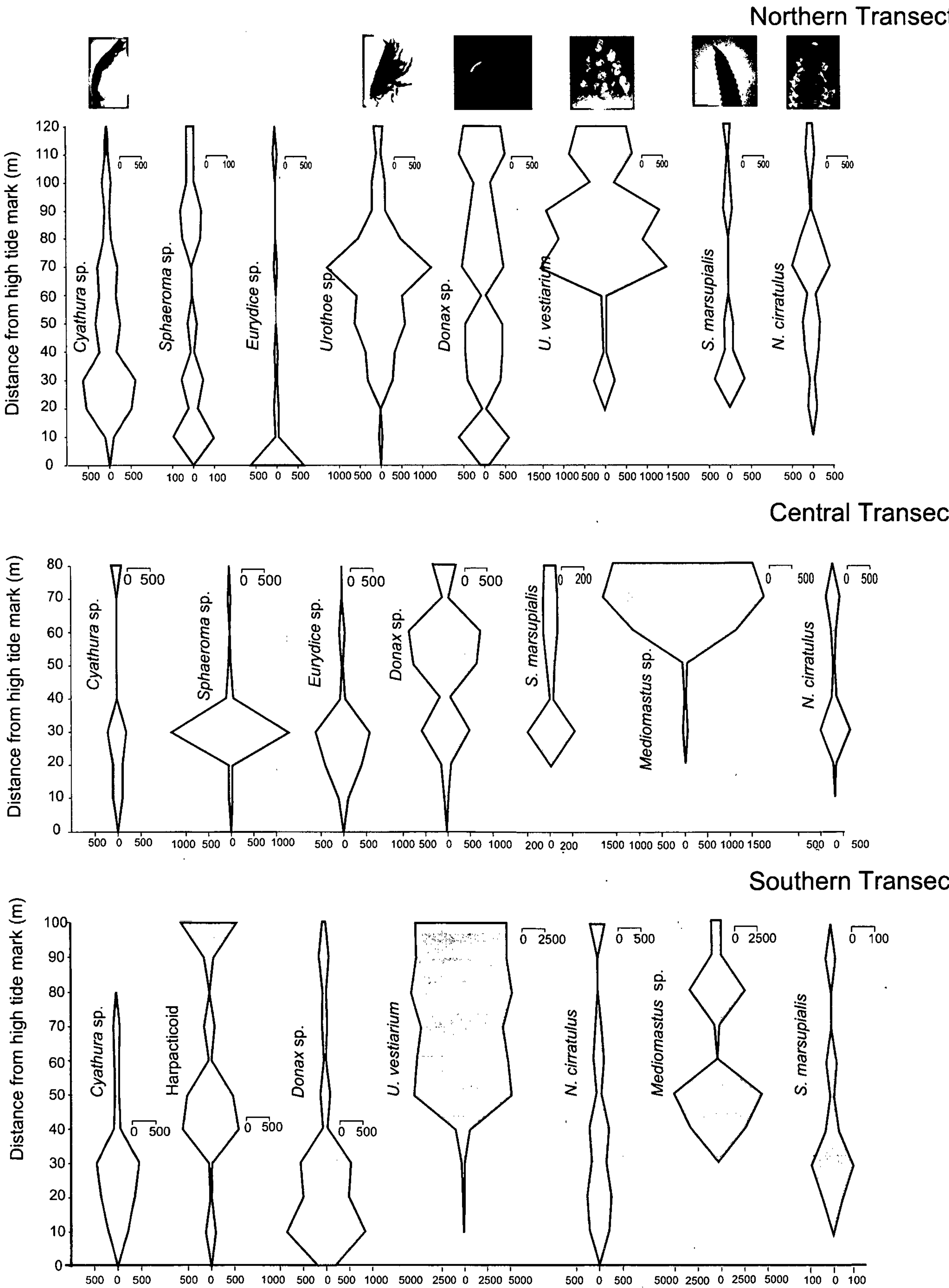


Fig 7.9 Kite diagram showing distribution and abundance (ind m^{-2}) of dominant species for the three transe

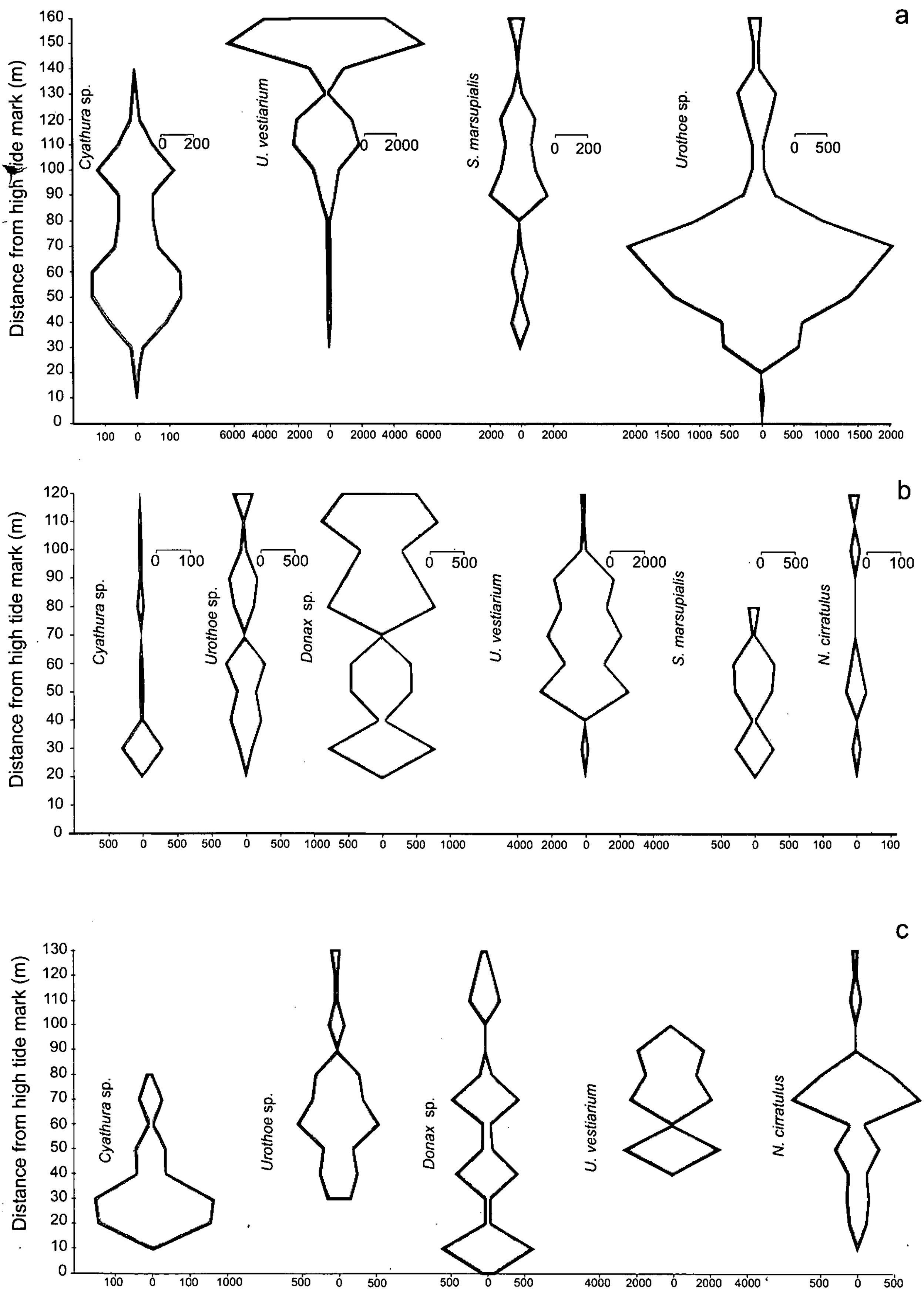
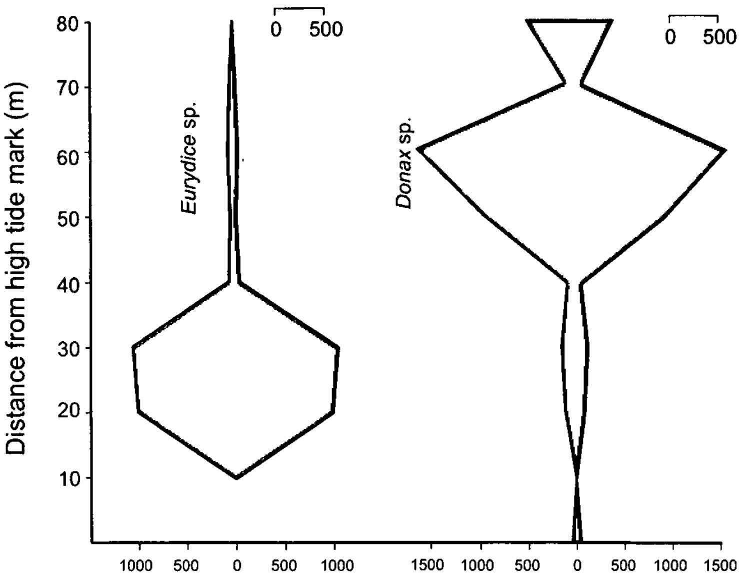


Fig. 7.10 Kite diagram of zonation and distribution of dominant species during premonsoon(a) monsoon(b) post monsoon(c)

a



b

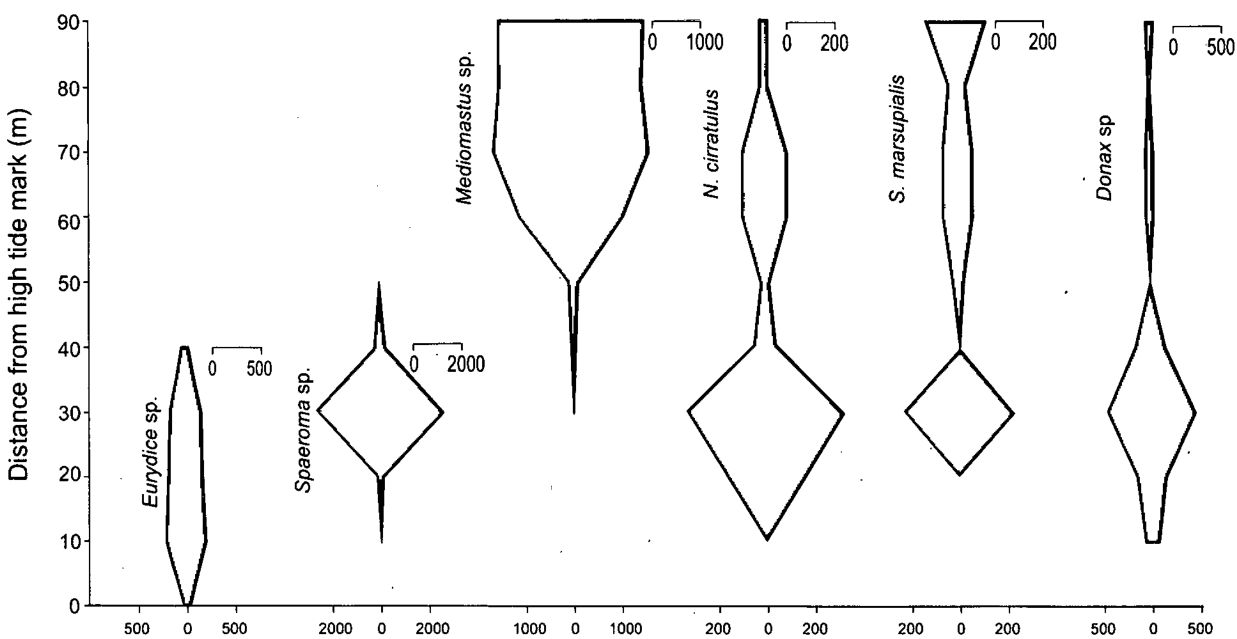


Fig. 7.11 Kite diagram of distribution of dominant species in the central transect during monsoon(a) and post monsoon(b)

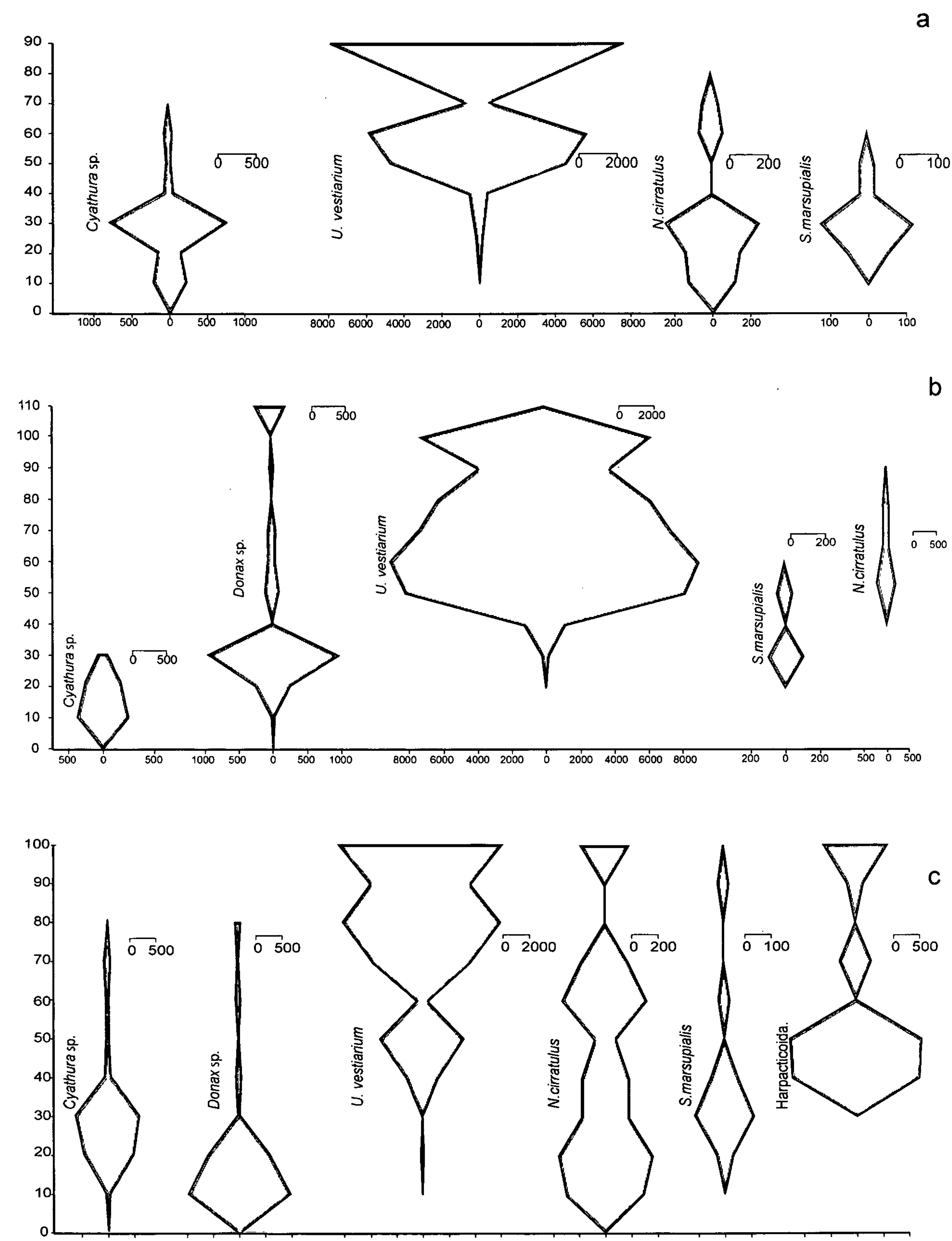


Fig. 7.12 Kite diagram showing the zonation and distribution of dominant species at the southern transect during premonsoon(a) monsoon(b) and post monsoon(c)

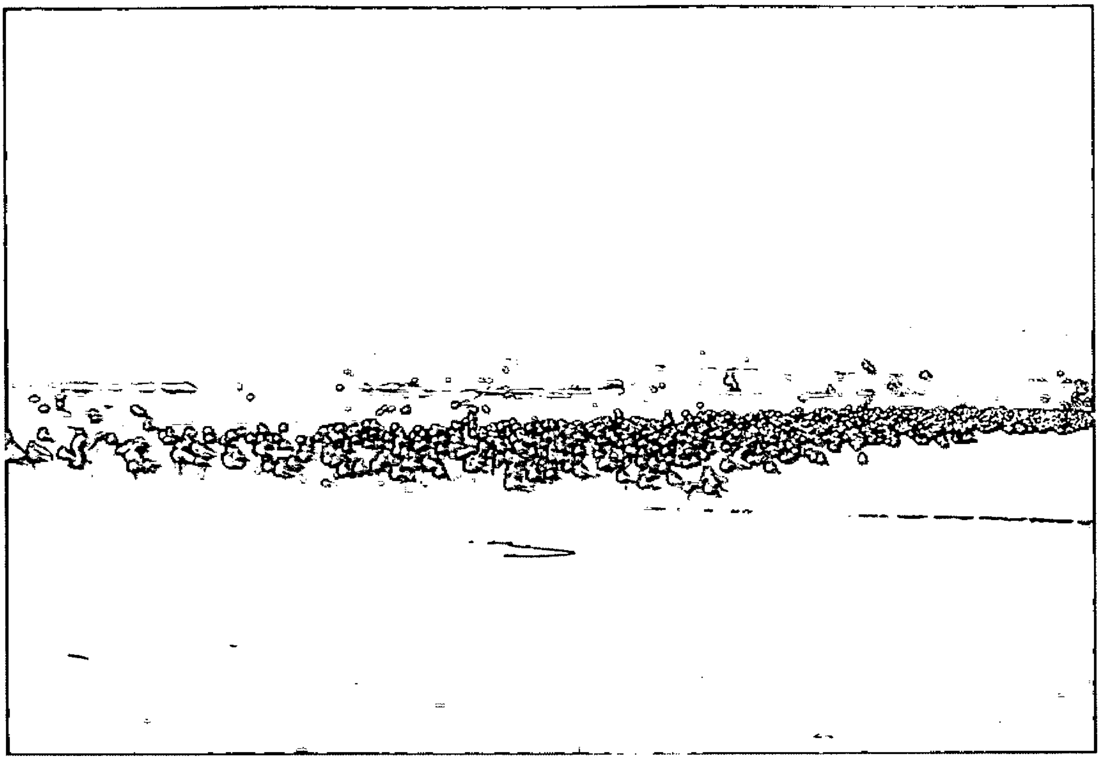


Fig 7.13 A Sea gulls on the Southern end of Kalbadevi Bay

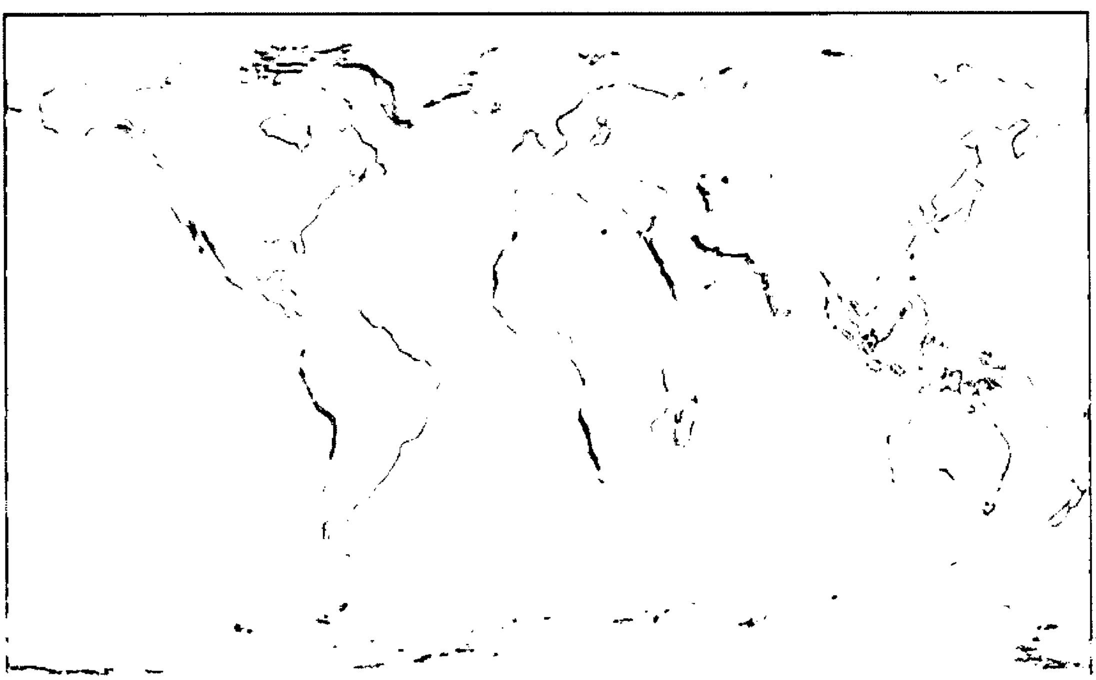


Fig 7.13B Global distribution of *U. vestiarium*
*source: wwwsealifebase.com

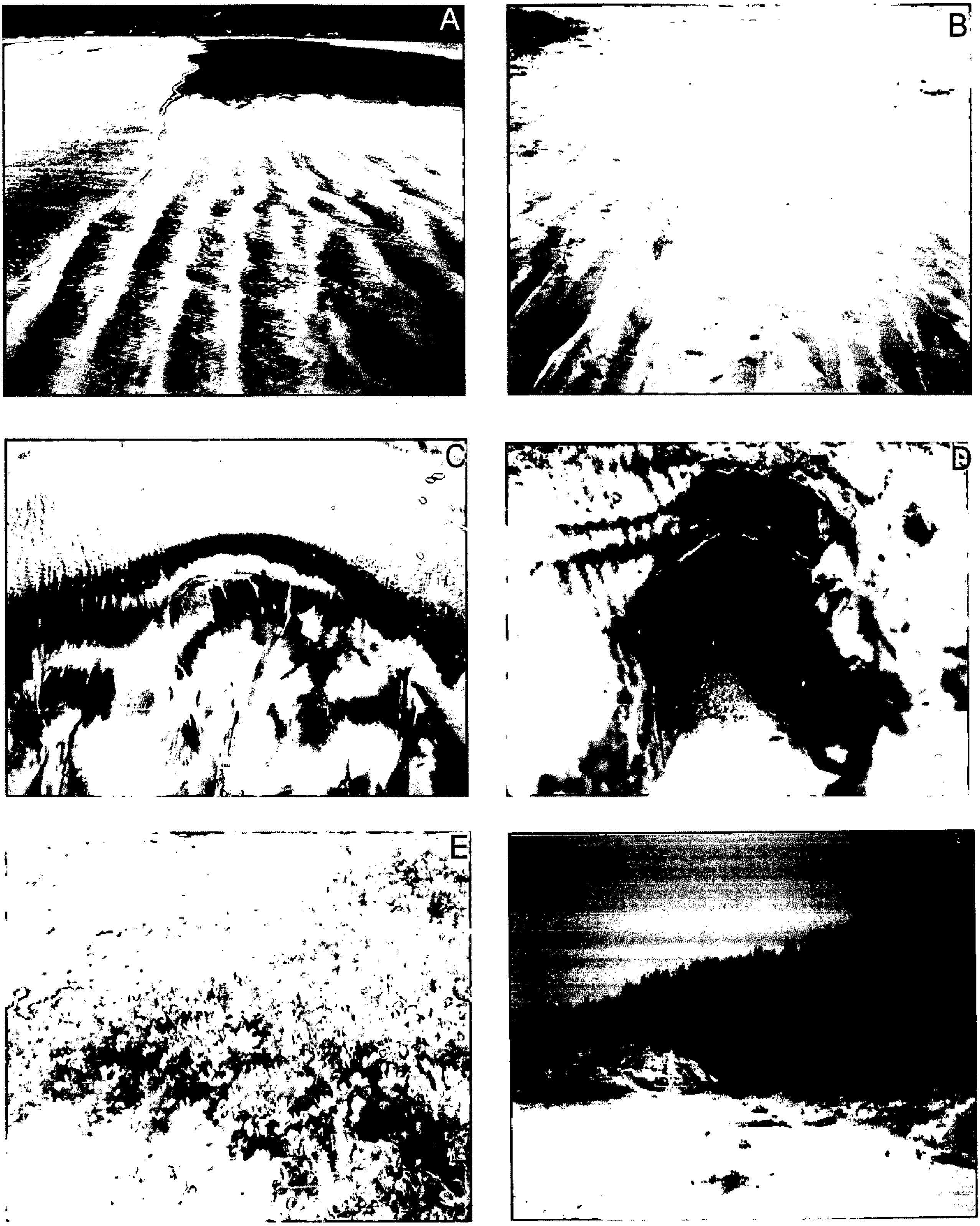


Plate 7.1 Illmenite deposit in intertidal region (a-d) and vegetation of Kalbadevi Bay

Plate 7.2 Sampling at Kalbadevi. Station marking (a-b). Macrofauna sample collection using quadrant and seiving (c-f).

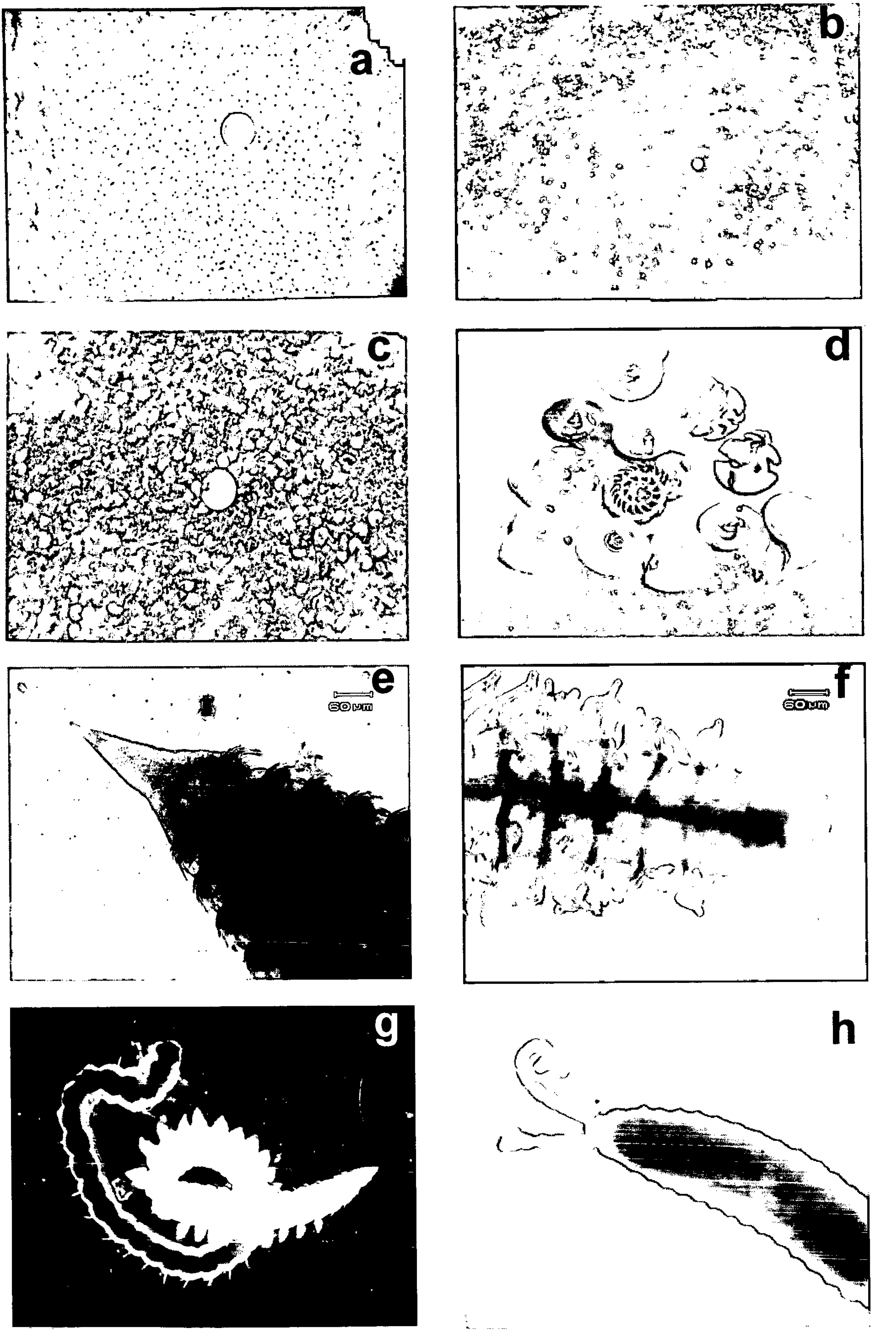


Plate 7.3: *U. vesitiarium* distribution in the intertidal zone (a-c), Colour pattern in *U.vestiarium* (d) Macrofauna of the area- *S. marsupialis* (e) *N.cirratulus*(f) *Levinsenia* sp.(g) and *Sacoccirus* sp.(h)

Chapter 8

Spatio-Temporal variability of macrofauna from the subtidal region of Kalbadevi Bay

8.1 Introduction

Development and disturbances are considered as contemporary activities. Therefore, mining minerals from the near shore areas may disturb the benthic habitat and cause irreversible damage to the coastal ecosystem. Today, it is not possible to discuss the development of any resources, without careful consideration of the environmental impacts. Hence, the EIA studies play a crucial role in protecting the coastal environment.

One of the greatest challenges when determining the impact benthic communities face from mining is the lack of baseline data and overall context in which benthic communities can be compared.

Due to the availability of high quantity of commercial grade minerals in the beach sediment, Kalbadevi Bay along the Ratnagiri coast is considered potential area for future placer mineral mining. The present study was carried out to (1) prepare the inventory of the benthic macrofauna (2) to study the seasonal abundance and distribution of macrofauna on the subtidal region, and (3) build a baseline data on the benthic community.

8.2 Materials and Methods

The sampling for the present study was carried out in the subtidal region of the Kalbadevi Bay (Fig 8.1). Sampling was carried out at five transect locations. However sampling in pre monsoon (May) and monsoon (September) was carried out only at OP/2 and OP/3. Sampling at each transect was carried out at water depth of 2m, 5m and 8m. Sediment samples were collected using the Van veen grab (0.04 m^2). Sediment for macrofauna was collected in duplicates and preserved in rose-bengal formalin solution. Sediment was collected separately for organic carbon and chlorophyll and preserved at low temperature.

Samples were processed following the methods described in Chapter 3.

8.3 Results

8.3.1 Environmental Parameters

During the baseline study, the water chl a ranged from 0.45- 1.19 μ g l^{-1} (Fig.8.2). High value was observed at OP/2/2 and OP/2/3. Chl *a* was low at stn OP/2/1. Seasonally, higher chl *a* was in pre monsoon (avg. 1.27μ g l^{-1}) and low (0.4μ g l^{-1}) during monsoon (Fig. 8.3 a). Phaeopigment was high in monsoon (0.16μ g l^{-1}) and low in pre monsoon. Sediment chl *a*, showed a similar pattern with high values during the pre monsoon (0.54μ g l^{-1}) and low during monsoon (0.19μ g l^{-1}; Fig. 8.3 b). The values for organic carbon ranged from 0.14 – 0.5% and high value was at OP/3/3 and low at OP/1/3 (Fig. 8.3b). Seasonally, OC was high during post monsoon (0.27%; Fig. 8.4). Data on nutrients and dissolved oxygen is summarised in table 8.1.

Granulometry analysis indicates little difference in the particle size and sediment composition. The sediment in the area was sandy (>95%) and silt fraction ranged from 0.2 – 2%. Silt content was higher at transect one (OP/1). The coarser fraction was higher at transect three (OP/3). The D_{50} value ranged from 88-172 μm. The sediment texture showed a marginal decrease in silt content during monsoon. In general, the sediment in the area was homogenous and can be described as well sorted with very fine sand (Table 8.2).

When the environmental parameters were correlated, organic carbon and sediment chl *a* showed a significant positive relation ($r=0.53$; $p<0.05$; Table 8.3a). PCA carried out to find the important variables in the study area. The first two components explained 84.4% variability (Table 8.3b). PC1 with 64% of the variability and was positively loaded by OC and silt loaded. Sand was negatively loaded on this component. PC2 showed 19.9% of the variability and chl *a* had the highest loading.

8.3.2 Macrobenthic community – Baseline data

The subtidal region of Kalbadevi bay had rich and abundant macrobenthic community. A total of 97 taxa were recorded from the total 128 taxa identified in the area throughout the study period. The polychaete with 79% of the total abundance was the dominant group. Crustacea with 13% of the abundance was the second dominant group. Bivalvia

(2.8%), Nematoda (2.8%) and Nemertenia (2%) were the other group. Other minor groups made to 1% of the macrofaunal abundance (Table 8.4).

In general, the faunal abundance ranged from 2375-33825 ind m^{-2} (18208±10554 sd; Fig. 8.5). The abundance was low at stn OP/4/3 and maximum value was at stn. OP/2/3. The most dominant species in the area was *Jasmineria* sp. which accounted to 32 % of the total macrofaunal abundance and was present at all the stations. High abundance of *Jasmineria* sp. was at OP/3/3 (16925 ind m^{-2}) and low at OP/4/3 (275 ind m^{-2}). *Mediomastus* sp. was next in dominance (22.7%). The higher abundance of 15075 ind m^{-2} was recorded at stn OP/2/3 and lower at OP/5/2 (150 ind m^{-2}). *Pseudopolydora* sp. (6%) ranged from 0-5675 ind m^{-2} with high abundance at OP/1/2 and OP/1/3. Abundance of unidentified Cirratulidae ranged from 0-4775 ind m^{-2} and highest abundance was at stn OP/2/3.

The amphiod, *Ampelisca* sp. and Cumacean belonging to family Bodotriidae were dominant among crustaceans. These species contributed to 3.8% each to the faunal abundance. *Ampelsica* sp. was reported at all the stations with high value at stn OP/2/2 (of 2300 ind m^{-2}). Cumacea (Bodotriidae) showed higher abundance at OP/5/1 (2425 ind m^{-2}) and OP/5/2 (2625 ind m^{-2}).

Macrofaunal abundance data was subjected to Bray-Curtis cluster and MDS ordination. As shown in figure 8.6a the entire study area was clustered at 40% similarity. All the stations clustered together at 56.5% similarity (Group I) except for stations in transect 3 and Stn OP/4/3. The stations in transect three clustered at 54.79% (Group II). Stn. OP/4/3 clustered with group I and II at 40.74%. The results of SIMPER giving the species that showed dissimilarity between the groups are summarized in Table 8.5. The MDS ordination reflected a similar grouping of the stations as seen in the cluster analysis (Fig.8.6b) except for the stations in transect three. Even though, same species were dominant at OP/3/2, their low abundance resulted in the separation of two stations. Species that separated the stations as group I and group II were *Eteone* sp. (3.88%), *Lumbroconereis latereli* (3.5%) and *P.coeca* (2.9%). Stn OP/4/3 was separated from the rest of the stations due to the low abundance and absence of Cumacea.

The macrofaunal biomass ranged from 1.16 g m^{-2} (OP/3/1) to 35.37 g m^{-2} (OP/3/1; Fig 8.7). Polychaeta was the major contributor (78%) to the faunal biomass, with higher biomass of 23.8 gm^{-2} at OP/3/1. Low polychaete biomass was recorded at stn OP/5/1 (0.275 gm^{-2}). Bivalvia accounted to 10.84% of the total biomass. Higher biomass was at OP/3/1 (7.05 gm^{-2}). Crustacean (8.4%) biomass ranged from 0.01 – 4.4 g m^{-2} recorded at stn OP/4/3 and OP/3/1, respectively.

The polychaeta also dominated in terms of faunal diversity with 55 taxa (55%). Amphipoda was next in dominance with 14% of the total identified species. Species number was low at OP/4/3 (14 taxa) and high at OP/2/3 (45 taxa). Species richness ranged from 1.8 -4.2 recorded at OP/4/3 and OP/2/3 respectively (Fig.8.8). Species number and richness did not show significant variation between the stations ($p>0.05$). Species evenness was higher at OP/5/2 (0.73) and lower at OP/3/3 (0.47) and varied significantly between the stations ($p<0.05$; Fig. 8.8b). Species diversity ranged from 1.5 – 2.5 recorded at stn OP/4/3 and OP/4/1, respectively (Fig.8.8c).

8.3.3 Spatial-Temporal variability of macrofaunal

To study the seasonal variation in benthic standing stock, only two transects i.e. OP/2 and OP/3 were considered. A total of 118 species were identified (Table 8.6). Average faunal abundance was higher in post monsoon (22579±12169 ind m^{-2}) and significantly low value were recorded during monsoon (4421± 4911 ind m^{-2}; Fig. 8.9). ANOVA and post hoc test showed significant seasonal variation ($p<0.05$). Polychaetes dominated the community with 81% of the total abundance and were the dominant group during all the three season. Further, the dominant species showed marked seasonal variation. *Jasmineria* sp. was the most dominant in post monsoon (36%) with abundance ranging from 2400-16925 ind m^{-2} (8233.33 ± 6826.4 sd). Maximum abundance was at stn OP/3/3 and minimum at OP/2/1. The species showed 99% reduction during pre monsoon with a mean density of 83±84 ind m^{-2} and was completely absent during monsoon. *Mediomastus* sp. (24.8%) was second dominant species during post monsoon with a mean abundance of 5645.8±5319 sd ind m^{-2}. The abundance of *Mediomastus* sp. also showed a decrease from pre monsoon to monsoon, however it remained to be dominant both during pre monsoon (50%; 6392±4353 ind m^{-2}) and monsoon (34%; 1488±1647 ind m^{-2}). The abundance of *Mediomastus* sp. ranged from 15075 ind m^{-2} at OP/2/3 (post monsoon) to 225 (OP/3/3) in monsoon. *Prionospio pinnata* though occurred in low abundance during post monsoon (104±53 ind m^{-2}) and pre monsoon (12±21) was the second dominant species in monsoon (31%; 1387±1403 ind m^{-2}). High abundance of *P. pinnata* was at OP/2/3 during monsoon. The other polychaete species in the area were unidentified Cirratulidae (4.6%), *Tharyx* sp. (1.7%), *Pseudopolydora* sp. (1.6%), *Polydora coeca* (1.3%), and *Magelona* sp. (1%).

Crustaceans made to 10% of the total faunal. *Cyathura* sp. (2.5%) was the most dominant crustacean. Abundance of *Cyathura* sp. showed an increase from 163 ± 151 ind m^{-2} during post monsoon to 808±583 ind m^{-2} in pre monsoon. In monsoon, the abundance declined to 45±48 ind m^{-2}. *Ampelisca* sp. contributed to 2.3 % of the total abundance followed by Cumacea (Bodotriidae1.6%) and followed a pattern similar to the other macrofauna i.e decline from post monsoon (442 ± 441 ind m^{-2}) to pre monsoon (221±216 ind m^{-2}) to a minimum abundance in monsoon (8±20 ind m^{-2}). *Ampelisca* sp. also showed a decline and was totally absent during the monsoon.

Nematoda is generally considered as meiofaunal taxa but large sized nematodes were found in substantial quantity (666±635 ind m^{-2}; 3.7%) in the subtidal sediment. Their abundance decreased from post monsoon (666±635 ind m^{-2}) to pre monsoon (562±770 ind m^{-2}) with a minimum value of 254±417 ind m^{-2} was recorded in monsoon. Species composition, feeding types and variation in their population over an annual cycle is studied by Nanajkar and Ingole (2008).

Bray-Curtis similarity analysis demarcated the area based on seasons. Post monsoon clustered at 48.8%, pre monsoon at 38.8% and monsoon at 32.77% (Fig.8.10). The clustering of post monsoon data was basically due to the dominance of *Jasmineria* which made 41.8% of the faunal abundance. *Mediomastus* sp. (23.3%) and unidentified Cirratulidae (8.7%) were the other dominant species. The species that dominated the macrofauna during pre monsoon were *Mediomastus* sp. (68.2%), *Cyathura* sp. (7.9%) and *Tharyx* sp. (6.1%). *Mediomastus* sp. (45%) and *P.pinnata* (44%) were the dominant during monsoon. The species that contributed to the dissimilarity between the seasons are given in Table 8.7

The faunal biomass ranged from 1.93- 15.56 g m^{-2}. High value was in post monsoon and lower in monsoon (Fig.8.11). ANOVA resulted in significant seasonal variation in biomass ($p<0.005$). Polychaeta was the dominant group during post monsoon (80%; 12.54 gm^{-2}) however their biomass reduced to 3.14 g m^{-2} (37%) and 0.66 g m^{-2} (34%) during pre monsoon and monsoon respectively. Post hoc test detected post monsoon biomass to be significantly higher. Maximum biomass value in all the three seasons was at OP/2/2 and OP/2/3. Polychaete biomass ranged from 0.18-23 g m^{-2} and was recorded at OP/3/1 during post monsoon and monsoon, respectively. Gastropod biomass showed an increase from post monsoon (0.12 g m^{-2}) to pre monsoon (2.69 gm^{-2}). Biomass of bivalves also showed an increase from post monsoon (1.9 g m^{-2}) to pre monsoon (2.17 g m^{-2}). Crustacean biomass showed a similar pattern of decrease from post monsoon (5.9 g m^{-2}) to pre monsoon (3 g m^{-2}) and low in monsoon (1 g m^{-2}). Biomass of the other groups showed an increase from post monsoon (0.37 g m^{-2}) to pre monsoon (1.7 g m^{-2}) with a marginal decrease in monsoon (1.02 g m^{-2}).

Polychaete dominated with 68 species followed by Amphipoda (16 taxa), Gastropoda (15 taxa) and Bivalvia (12 taxa). The value for species number and richness was high during post monsoon (78 and 3.3) and pre monsoon (82 and 3.7) and low during monsoon (41 and 1.5) and showed significant seasonal variation ($p<0.001$) but did not differ spatially ($p>0.05$). Species evenness did not show significant seasonal variation ($p>0.05$) and values were 0.6 in pre- and post monsoon and 0.65 in monsoon (Fig.8.12b). Evenness showed significant variation between the stations ($p<0.05$). Shannon-Wiener diversity ranged from 1.5 (monsoon) to 2.1 (post- and pre monsoon; Fig. 8.12c). The values showed significant seasonal variation ($p<0.05$) but did not vary spatially.

8.3.4 Correlation between environmental and biological parameter

The correlation between the environmental and biological parameter is summarized in table 8.8a. Sedimentary organic carbon showed a significant correlation with macrobenthic abundance ($r=0.69$' $p=0.001$), biomass ($r=0.50$; $p=0.021$), species richness ($r=0.79$; $p< 0.001$). Species evenness showed a weak negative correlation with OC ($r= -0.40$; $p >0.05$), whereas diversity showed a non significant positive correlation with OC ($r=0.42$; $p>0.05$). Chl *a* (sediment and water) showed significant positive correlation with richness ($r=0.52$; $p=0.015$). Abundance and biomass was also correlated with Chl-*a*, however not statistically significant (Table 8.8). Further, the sand fraction had significant negative correlation with species number ($r=0.66$; $p=0.001$) and abundance ($r=0.43$; $p<0.05$). Evenness showed a significant positive correlation with coarse sand. Diversity showed a trend similar to species number, with significant positive correlation with silt and negative with sand. Biomass was positively related to coarser sand.

The BIOENV analysis confirmed that sediment organic carbon and silt have significant influence on the macrobenthic community (abundance, biomass; diversity and species richness, $\rho=0.59$). BIOENV was also carried out between the environmental parameter and the dominant species. The analysis gave a similar result indicating OC and silt as important parameter ($\rho=0.55$).

8.4 Discussion

The main purpose of any EIA study is to determine the natural variability in background environmenta and biotic conditions against the potential changes caused by anthropogenic activities such as dredging, dumping or mining. The results presented here are part of an EIA study carried out to build a baseline data coastal environment of Kalbadevi Bay.

The sediment texture in the area was well sorted and dominated by very fine sand. During the monsoon, the sand showed marginal increase compared to pre monsoon with a subsequent decrease in the silt content. In general, the sediment composition was similar during both the seasons with marginal seasonal variation. Chl *a* was high in surface water indicating high primary productivity. Two creeks with luxuriant mangrove vegetation in the periphery drain into the Kalbadevi bay. It brings concentrated nutrients into the bay which helps in increasing the primary productivity. Dissolved nutrients are considered to be the limiting factor for primary production (Graneli et al. 1986). Hence, increased river flow during monsoon enhances the nutrient transport from rivers into the coastal zone (Langland et al. 2001; Justic et al. 2003), contributing to a variety of biological and biogeochemical responses such as increased primary production and benthic nutrient recycling (Boynton and Kemp 2000).

Coastal areas are known to have ecological linkages with adjacent ecosystems such as mangroves, estuaries and coastal lagoons (Short and Hesp 1982). Mangrove forests are dominant ecosystems along most tropical coastlines and play a key role in supporting coastal fisheries, both by serving as a habitat and by nutrient exchange (Qasim and Wafar 1990). The latter role is of particular interest because it provides a clear linkage between intertidal forests and adjacent coastal waters. An increasing number of studies have investigated the influences of mangrove forests on coastal nutrient cycles and food chains (Nixon et al. 1984; Rodelli et al. 1984; Boto et al. 1991). Therefore, high chlorophyll in the area may be due to higher phytoplankton biomass resulting from influx of nutrients from the adjacent mangroves.

Organic carbon was high and can be attributed to the high primary productivity. Chl *a* and OC showed a significant positive correlation. Several studies have shown a direct relationship between sediment organic carbon and planktonic production (Davies and Payne 1984). Thus, organic matter being flushed from the adjacent mangrove habitat could undoubtedly contribute to the higher organic carbon. The export of carbon to the adjacent ocean may be one of the dominant outputs of material from the mangroves accounting for >80% of total organic carbon export in some cases (Furukawa et al. 1997; Machiwa and Hallberg 2002).

The macrobenthic community of the area was dominated by polychaetes and crustaceans, common characteristics of sandy subtidal habitats. The macrobenthos was represented by 128 taxa. The macrobenthic community of the area comprised of high number of species and abundance compared to other areas along the central west coast of India (Ansari and Parulekar 1977; Harkantra and Parulekar 1981). The high abundance could be due to the food availability (organic carbon and phytoplankton) and the sediment texture. The community was dominated by filter feeders like *Jasmineria* sp., Cumacean, Bivalvia and deposit feeders (Capitellidae, Spionidae and Cirratulidae).

The overall relationships between biotic and abiotic parameters (Table 8.8) indicated that sediment OC and texture had significant influence on the biotic parameters such as species number, richness, abundance and biomass. The rank correlation analysed with BIOENV confirmed the importance of OC and sediment texture in influencing the macrofauna. Grain size or granulometry is considered important for determining the benthic community (Sanders 1958; Rhoads 1974; Wijsman et al. 1999). In general, the low diversity is observed in mud, high in sandy habitat and highest in mixed sediment type with median particle diameters of 200μm (Gray 1974).

The macrofauna showed subtle variation between the stations. This may be because the sediment texture was homogenous and OC values were also high in all transects. *Jasmineria* sp. was the dominant during the post monsoon which comprised 32% of the total population. *Jasmineiria* sp.1 was also found to be the most dominant on the south west coast of UK (Gobin and Warwick 2006). It belongs to the family Sabellidae and is comprised of tubiculous filter feeding organisms (Fauchald and Jumars 1979). Major food includes pelagic diatoms, dinoflagellates, and other unicellular algae as well as invertebrate larvae. *Jasmineria* sp was found in higher abundance during post monsoon and the community was dominated by juveniles (>80%) indicating that the recruitment for *Jasmineria* sp. occur during late post monsoon. Most sabellids show a wide range of reproductive strategies from planktonic larvae to direct development (Fauchald and Jumars 1979). Spawning is mostly polytelic to continuous reproductive events. *Mediomastus* sp. showed a more even distribution and was the dominant during pre monsoon and monsoon. *Mediomastus* sp. is known to dominate in high energy sandy environment (Rivero et al. 2005). In fact, species belonging to the genus *Mediomastus* sp. flourish in habitat with moderate amount of organic matter with total absence in area of high organic pollution (Pearson and Rosenberg 1978). The Kalbadevi Bay with fine sand and high organic carbon seems to provide an ideal habitat for *Mediomastus* sp. Capitellids are non- selective deposit feeders. Most of the species are motile but tube building forms were also recorded. This family also showed diverse reproductive strategy and may display continuous or seasonal spawning.

The macrobenthic community showed a strong temporal variability with higher abundance during pre- and post monsoon and lower during monsoon. Increase in faunal abundance from post to pre monsoon and reduction in monsoon is a typical pattern in the tropical estuaries. Pannikar (1969) postulated that the heavy monsoonal runoff causes the defaunation of the coastal and estuarine benthic community followed by recolonisation brought by recruitment in the post monsoon. Further, Ingole and Parulekar (1998) suggested that increased salinity during pre monsoon triggers the reproductive activity of euryhaline benthic species.

8.5 Conclusion

The macrobenthic community of the area was found to be homogeneous and was dominated by deposit and filter feeding species. Macrofaunal community showed temporal variation which was due to the natural process of recruitment rather than any biological or physical factors. The homogeneity of the sediment texture and availability of food could be the possible factor influencing the community of the area. Therefore it can be concluded that the subtidal region of Kalbadevi is homogenous and dominated by deposit feeders and filter feeders. It indicated that in spite the fact that benthic conditions in the nearby Ratnagiri harbor are deteriorating (Ingole et al. 2008), the environmental conditions in Kalabdevi bay are stupendously ideal for benthic colonization.

Table 8.1
Environmental parameters of Kalbadevi Bay

	Post Monsoon	Pre Monsoon	Monsoon
*TSM (mgl^{-1})	0.5-3.6		0.4-5
*DO ($mg\ l^{-1}$)	2.8-3.7	2-3.6	0.3-4.97
*Phosphate ($\mu\ M\ l^{-1}$)	0-0.14	0.13-0.22	0.09-0.44
*Nitrite ($\mu\ M\ l^{-1}$)	0.08-0.26	0-0.04	0-0.47
*Nitrate ($\mu\ M\ l^{-1}$)	0.2-3.27	0.24-0.8	0.24-4.4
Water Chl a ($\mu g\ l^{-1}$)	0.02-1.2	1.0-1.67	0.28-0.68
Water Phaeophytin ($\mu g\ l^{-1}$)	0-0.1	0	0-0.39
Sediment Chl a ($\mu g\ g^{-1}$)	0.1-0.59	0.15-0.7	0.08-0.28
Sediment Phaeophytin ($\mu g\ g^{-1}$)	0.3-1.7	0.1-0.45	0-0.48

*Source: Anon 2006

Table 8.2
Sediment texture (%) for the subtidal stations of Kalbadevi

	D_{50} (µm)	Sand	Mud	V Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	V Fine Sand	V Coarse Silt
Post monsoon									
OP/1/1	89	98.3	1.7	0.0	0.0	1.5	2.7	94.2	1.7
OP/1/2	88	98.2	1.8	0.0	0.0	0.0	0.3	97.9	1.8
OP/1/3	88	98.5	1.5	0.0	0.0	0.0	1.0	97.4	1.5
OP/2/1	89	98.5	1.5	0.0	0.0	0.1	2.2	96.2	1.5
OP/2/2	89	98.3	1.7	0.0	0.0	0.3	2.3	95.7	1.7
OP/2/3	92	98.9	1.1	1.9	1.9	1.4	5.3	88.3	1.1
OP/3/1	100	99.1	0.9	0.5	0.4	1.0	24.9	72.3	0.9
OP/3/2	96	99.0	1.0	0.0	0.5	0.8	18.3	79.4	1.0
OP/3/3	95	99.0	1.0	3.3	1.3	1.2	12.6	80.6	1.0
Pre Monsoon									
OP/2/1	89	98.3	1.7	0.0	0.0	0.0	3.4	94.8	1.7
OP/2/2	88	98.3	1.7	0.0	0.0	0.1	1.5	96.7	1.7
OP/2/3	88	98.3	1.7	0.0	0.0	0.0	0.5	97.8	1.7
OP/3/1	92	98.8	1.2	0.8	0.8	0.2	9.9	87.0	1.2
OP/3/2	92	98.9	1.1	0.0	0.1	0.1	11.4	87.4	1.1
OP/3/3	90	98.7	1.3	0.0	0.0	0.1	7.9	90.7	1.3
Monsoon									
OP/2/1	123	99.4	0.6	0.0	1.3	4.9	42.8	50.4	0.6
OP/2/2	88	98.8	1.2	0.0	0.0	0.1	1.3	97.3	1.2
OP/2/3	90	98.9	1.1	0.0	0.0	0.4	5.9	92.4	1.1
OP/3/1	172	99.8	0.2	0.0	0.3	10.1	73.6	15.8	0.2
OP/3/2	173	99.8	0.2	0.0	0.4	6.0	81.6	11.8	0.2
OP/3/3	101	99.1	0.9	0.0	0.3	4.0	24.4	70.3	0.9

Table 8.3a
Pearson Correlation of environmental parameter (N=21). Values in bold are significant ($p<0.05$)
W=water, S sediment.

	OC	S Chl	S Phaeo	W Chl a	W Phaeo	DO	PO_4	NO_2	NO_3	% Sand	% Mud
OC	1.00	**0.54**	**0.69**	0.44	-0.07	0.42	**-0.52**	-0.03	-0.24	**-0.6**	**0.6**
S Chl a	**0.54**	1.00	0.32	**0.61**	-0.32	0.30	0.04	**-0.51**	-0.34	-0.4	0.4
S Phaeo	**0.69**	0.32	1.00	0.23	0.08	0.43	**-0.57**	0.07	-0.13	-0.3	0.3
W Chl *a*	0.44	**0.61**	0.23	1.00	**-0.60**	0.20	-0.04	**-0.52**	-0.41	**-0.6**	**0.6**
W Phaeo	-0.07	-0.32	0.08	**-0.60**	1.00	-0.25	-0.14	0.22	-0.07	**0.5**	**-0.5**
DO	0.42	0.30	0.43	0.20	-0.25	1.00	-0.34	-0.14	-0.44	-0.3	0.3
PO_4	**-0.52**	0.04	**-0.57**	-0.04	-0.14	-0.34	1.00	-0.29	0.01	0.3	-0.3
NO_2	-0.03	**-0.51**	0.07	**-0.52**	0.22	-0.14	-0.29	1.00	0.34	0.0	0.0
NO_3	-0.24	-0.34	-0.13	-0.41	-0.07	-0.44	0.01	0.34	1.00	0.3	-0.3
% Sand	**-0.59**	-0.37	-0.27	**-0.63**	**0.54**	-0.27	0.31	0.00	0.30	1.0	**-1.0**
% Mud	**0.59**	0.37	0.27	**0.63**	**-0.54**	0.27	-0.31	0.00	-0.30	**-1.0**	1.0

Table 8.3b
PCA for environmental parameters

Variable	**PC1**	**PC2**
OC	**0.37**	0.24
S Chl a	**0.30**	-0.23
S Phaeo	0.28	**0.39**
W Chl a	0.38	-0.29
W Phaeo	-0.23	0.34
DO	0.28	0.13
PO_4	-0.17	**-0.54**
NO_2	-0.13	**0.474**
NO_3	-0.24	0.08
% Sand	**-0.39**	-0.01
% Mud	**0.39**	0.01
Eigen values	4.6	2.18
%Variation	41.8	19.8
Cum.% Variation	41.8	61.7

Table 8.4

Macrobenthic group abundance in the subtidal area at the baseline stations

Taxa	OP/1/1	OP/1/2	OP/1/3	OP/2/1	OP/2/2	OP/2/3	OP/3/1	OP/3/2	OP/3/3	OP/4/1	OP/4/2	OP/4/3	OP/5/1	OP/5/2	OP/5/3
Foraminifera	0	0	0	0	0	0	0	0	0	0	150	0	0	0	375
Coelentrata	0	75	125	0	50	0	0	0	25	0	0	0	0	0	0
Nematoda	575	25	1300	1525	0	1125	375	0	975	400	250	50	25	25	900
Nemertinea	550	475	700	75	500	200	100	275	175	1250	375	100	375	350	0
Polychaeta	7050	14300	16700	6800	22100	30800	22900	2975	29900	5975	23575	2150	6300	2975	21075
Oligochaeta	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia	75	2625	425	100	275	225	175	225	200	1350	775	0	800	0	500
Gastropoda	0	25	0	0	0	0	25	25	100	0	0	0	25	0	250
Cumacea	625	400	75	825	850	50	1250	50	125	775	875	0	2550	2775	1000
Isopoda	200	0	0	175	300	400	50	50	75	25	225	0	400	300	600
Tanaidacea	75	225	25	100	75	200	0	25	100	25	150	0	100	0	75
Amphipoda	750	2150	450	750	3525	750	1575	950	825	375	2050	75	1275	1525	1725
Decapoda	0	0	0	0	25	0	25	0	0	0	0	0	25	0	0
Ostracoda	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0
Harpacticoida	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0
Ophiuroidea	150	0	0	0	25	50	25	0	0	50	0	0	25	0	0
Amphioux	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8.5
Macrofaunal species in the subtidal region of Kalbadevi Bay

Taxa	Post monsoon	Pre monsoon	Monsoon
Foraminifera	+	+	+
Coelentrata			
Hydroid	+	-	+
Obelia colony	+	+	-
Nematoda	+	+	+
Nemertenia	+	+	+
Polychaeta			
Hesione sp.	+	-	-
Micropthalamus sp.	-	+	-
Exogene sp.	+	-	-
Ancistrasyllis sp.		-	+
Nereis sp.1	+	-	+
Nereis sp.2	+	-	-
Perinereis sp.	+	-	-
Eteone sp.	+	+	-
Phyllodoce sp.1	+	-	-
Phyllodoce sp.2	+	-	-
P. castnae	+	+	-
P. gracilis	+	-	-
Odontosyllis sp.	+	-	-
Lumbriconereis impatiens	+	-	-
L. latrelli	+	+	-
L.bifliaris	-	+	+
Lumbriconereis sp.	+	+	-
Glycera alba	+	+	+
Glycera longipinnis	+	+	-
Glycera prashadii	+	+	-
Glycinde oliogodon	+	+	-
Goniadidies sp.	+	-	-
Cossura sp.	+	+	-
Cirratulidae (Unidentified)	+	+	-
Tharyx sp. 1	+	+	+
Tharyx sp.2	-	+	+
Nephtys polybranchia	+	+	+
N. oligobranchia	-	+	-
Magelona sp.	+	+	+
Aricidea sp.	+	+	+
A. catherina	+	+	+
Levinsenia sp.	+	+	-
Dorivella mandapmae	+	+	+
Lysidice sp.	+	-	-
Dioptra clapaderii	+	+	+
Onuphis eremita	+	+	+
Onuphis holobranchiata	+	-	-

Contd....

Taxa	Post monsoon	Pre monsoon	Monsoon
Eunice indica	+	+	-
Aricia sp.	+	-	-
Scoloplos sp.	+	+	+
Scoloplos marsupialis	-	+	-
Prionospio pinnata	+	+	+
Prionospio sp.	+	-	-
Minuspio cirrifera	+	+	+
Polydora coeca	+	+	
Pseudopolydora sp.	+	+	+
Capitella minima	+	-	-
Mediomastus sp.	+	+	+
Euclymene insecta	+	-	-
Axiothella sp.	+	+	-
Magelona sp.	+	-	-
Armandia lanceolata	+	+	-
Flabergiidae (Unidentifed)	+	-	-
Poecoelochaetus serpens	-	+	+
Phyllochaetopterus socialis	+	+	-
Disoma orissae	-	-	+
Owenia sp.	-	+	-
Sternapsis scutata	+	+	+
Jasimenaria sp.	+	+	-
Terebellidae (Unidentifed)	+	+	-
Terebellides sp.	+	+	-
Terebellides stromiae.	+	-	-
Amage sp.	+	+	-
Oligochaeta	+	-	+
Sipuncula	-	+	-
Phoronida	-	+	-
Bivalvia	+	-	-
Nuculana sp.	+	-	-
Modilous sp.	+	+	-
Cardiata bicolor	-	+	-
Cuspidaria sp.	-	+	-
Donax sp.	-	+	-
Venerupis	-	-	+
Chione scabra	+	+	+
Tellina ala	+	+	-
Mactra sp.	-	+	-
Solen sp.	+	-	-
Unidentified bivalavia	+	-	+
Gastropoda	+	-	-
Babylonia spirata	+	+	-
Cerithidae (Bittium)	-	+	-
Gibberula sp.	-	+	+
Umbonium vestiarium	-	+	-
Turitella sp.	-	+	-
Retusa sp.	-	+	-

Contd...

Taxa	Post monsoon	Pre monsoon	Monsoon
Olivia sp.	-	+	+
Cyprae sp.	-	+	-
Polinices sp.	-	+	-
Surcula sp.	-	-	+
Calyptra sp.	+	-	-
Cylicha sp.	+	-	-
Ovulum sp.	+	-	-
Mitirdae	-	-	+
Gastropoda (Unidentified)	+	+	-
Cumacea	+		-
Cumacea #1(Bodotriidae)	+	+	+
Cumacea #2	+	+	+
Isopoda	+	-	-
Cyathura sp.	+	+	+
Isopoda (Unidentified)	+	+	+
Tanaidacea			
Tanaidacea1	+	-	-
Tanaidacea2	+	-	-
Amphipoda	+	-	-
Ampelisca sp.	+	+	-
Synchelidium sp.	+	+	-
Haustoridea	+	+	+
Ampithoe sp.	+	+	-
Photis sp.	+	+	+
Gammarus sp.	-	+	-
Isaeidae 1	+	-	-
Isaeidae 2	+	-	-
Melphidippidae	+	+	-
Liljeborgidae	+	-	-
Stegocephalidae	+	-	-
Corophidae	-	+	-
Phoxocephalidae	+	+	-
Amphipoda 1	+	-	-
Amphipoda 2	+	-	-
Caprellidae	+	-	-
Decapoda			
Unidentified Decapoda	+	+	-
Eupagrus sp.	+	+	+
Penaidae	-	+	-
Ostracoda	+	+	-
Harpacticoida	+	-	-
Ophiuroidea	+	-	-
Cephalochordata			
Branchiostoma lancelotum	+	-	-

Table 8.6
SIMPER results showing dissimilarity among groups based on cluster analysis

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Av. dissimilarity 48.77						
	Group 1	**Group 3**				
Eteone sp.	0	6.12	1.89	8.24	3.88	3.88
Isaeidae 1	4.63	0	1.46	3.99	3	6.88
L. latrelli	4.58	0	1.42	2.33	2.91	9.79
P. coeca	4.37	2.23	1.23	1.15	2.53	12.32
Ampithoe sp.	0	3.94	1.23	6.74	2.52	14.84
Tellina sp.	4.58	1.09	1.19	1.6	2.43	17.27
Photis sp.	0	2.98	1.02	1.29	2.09	19.37
Nematoda	5.09	4.27	1.02	1.05	2.08	21.45
Av. dissimilarity 58.40						
	Group 1	**Group 2**				
Cumacea #1	5.77	0	2.65	2.08	4.54	4.54
Cirratulidae	5.3	0	2.33	2.61	3.99	8.53
Isaeidae 1	4.63	0	2.05	5.01	3.52	12.04
Phyllodoce sp.1	4.8	0	2.02	1.89	3.46	15.5
Cyathura sp.	4.44	0	2.01	1.79	3.45	18.95
Tellina sp.	4.58	0	1.97	2.37	3.38	22.33
C. scabra	4.55	0	1.94	1.73	3.32	25.65
Cumacea #2	4.18	0	1.92	1.89	3.29	28.94
Tanaidacea1	4	0	1.72	2.64	2.94	31.88
Cossura sp.	0.36	3.93	1.64	2.71	2.81	34.69
P. coeca	4.37	3.26	1.53	2.98	2.63	37.31
Nephtys sp.	3.23	0	1.42	1.74	2.44	39.75
Pseudopolydora sp.	5.74	3.26	1.37	2.02	2.34	42.1
Ampelisca sp.	6	3.26	1.22	1.72	2.1	44.19
Scoloplos sp.	2.82	0	1.22	1.16	2.08	46.28
Av. dissimilarity 62.39						
	Group 3	**Group 2**				
Cirratulidae	7.04	0	3.27	6.96	5.25	5.25
Eteone sp.	6.12	0	2.81	12.73	4.5	9.75
Cumacea #1	5.18	0	2.39	4.25	3.83	13.58
C. scabra	4.84	0	2.37	2.27	3.81	17.39
L. latrelli	0	4.33	2.08	3.14	3.34	20.73
Cossura sp.	0	3.93	1.89	3.14	3.03	23.76
Nephtys sp.	4.01	0	1.87	5.63	2.99	26.75
Ampithoe sp.	3.94	0	1.84	5.69	2.94	29.69
Cyathura sp.	3.71	0	1.74	5.01	2.79	32.48
Photis sp.	2.98	0	1.59	1.05	2.56	35.04
P. coeca	2.23	3.26	1.59	3.32	2.55	37.58
Isaeidae 2	0	3.26	1.57	3.14	2.51	40.09
Nematoda	4.27	3.93	1.51	1.59	2.41	42.51

Table 8.7
SIMPER results showing dissimilarity among groups based on cluster analysis

Av.dissimilarity 73.77	**Group 1**	**Group 2**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Jasimenaria sp.	8233.33	83.33	21.51	1.59	29.16	29.16
Mediomatus sp.	5645.83	6391.7	15.21	1.23	20.62	49.78
Cirratulidae	1816.67	12.5	4.61	1.55	6.25	56.03
Cyathura sp.	162.5	808.33	2.51	1.06	3.4	59.43
Nematoda	666.67	562.5	2.38	0.96	3.22	62.65
Ampelisca sp.	837.5	75	2.33	1.24	3.16	65.81
Tharyx sp. 1	0	641.67	2.12	0.93	2.88	68.69
Av. dissimilarity 88.17	**Group 1**	**Group 3**				
Jasimenaria sp.	8233.33	0	29.85	1.86	33.86	33.86
Mediomatus sp.	5645.83	1487.5	16.35	1.38	18.55	52.41
Cirratulidae	1816.67	0	6.32	1.86	7.17	59.57
P. pinnata	104.17	1387.5	5.39	0.94	6.11	65.68
Ampelisca sp.	837.5	0	4	1.21	4.54	70.22
Nematoda	666.67	254.17	3.02	0.79	3.42	73.64
Pseudopolydora sp.	475	112.5	1.97	1.47	2.24	75.88
Cumacea #1	441.67	8.33	1.88	1.04	2.13	78.01
Av dissimilarity 79.65	**Group 2**	**Group 3**				
Mediomatus sp.	6391.67	1487.5	29.55	1.65	37.1	37.1
P. pinnata	12.5	1387.5	7.22	1.29	9.07	46.17
Cyathura sp.	808.33	45.83	5.49	1.33	6.89	53.06
Tharyx sp.	641.67	54.17	3.97	0.99	4.98	58.05
Nematoda	562.5	254.17	3.24	0.88	4.07	62.12

Table 8.8
Correlation between benthic and environmental parameters. Values in bold area significant at $p<0.05$. S: sediment; W: water.

	OC	S Chl a	W Chl a	% Sand	% Mud
Species Number	**0.79**	0.36	**0.52**	**-0.67**	**0.67**
Abundance	**0.69**	0.11	0.19	**-0.44**	**0.44**
Biomass	**0.50**	0.09	0.16	-0.09	0.09
Species richness	**0.77**	0.40	**0.57**	**-0.67**	**0.67**
Evenness	-0.41	-0.36	-0.31	0.43	-0.43
Diversity	0.42	0.02	0.29	**-0.47**	**0.47**

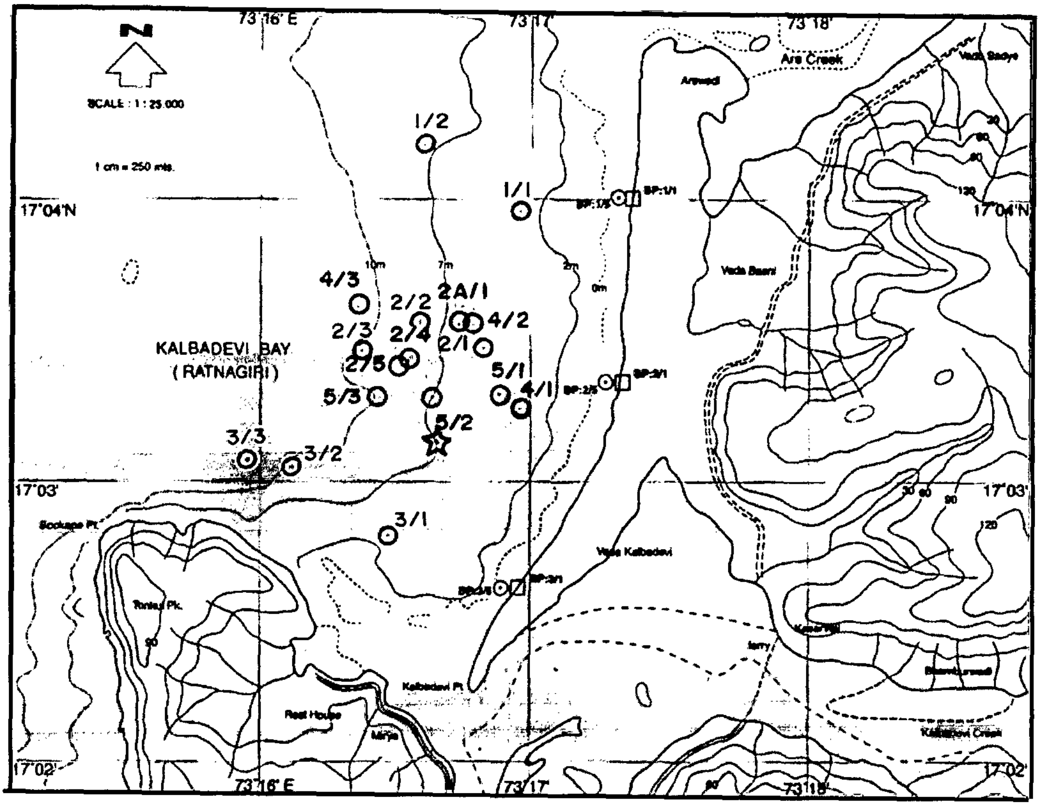


Fig 8.1 Location of sampling stations in the subtidal region of Kalbadevi

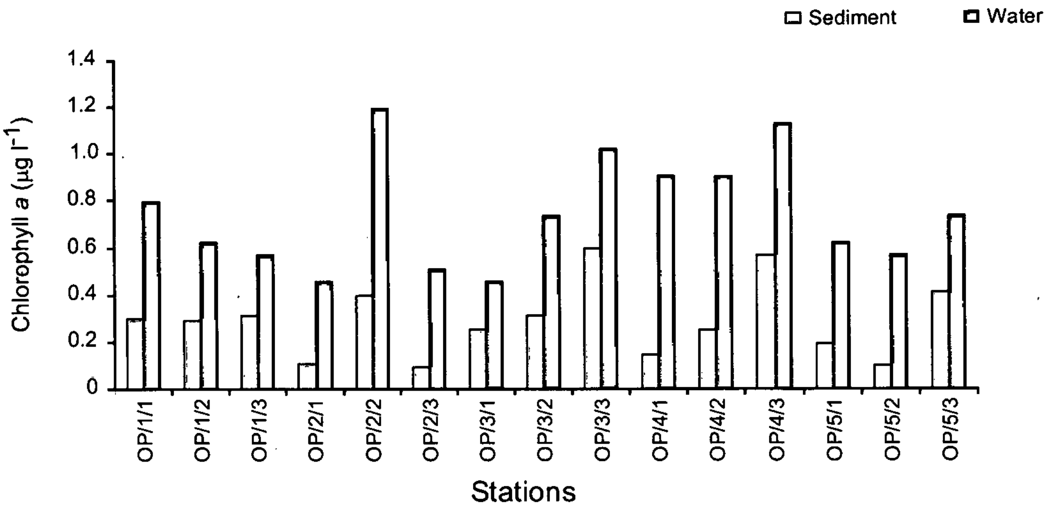


Fig 8.2 Variation in sediment and water chl *a* ($\mu g\ l^{-1}$) at the baseline stations

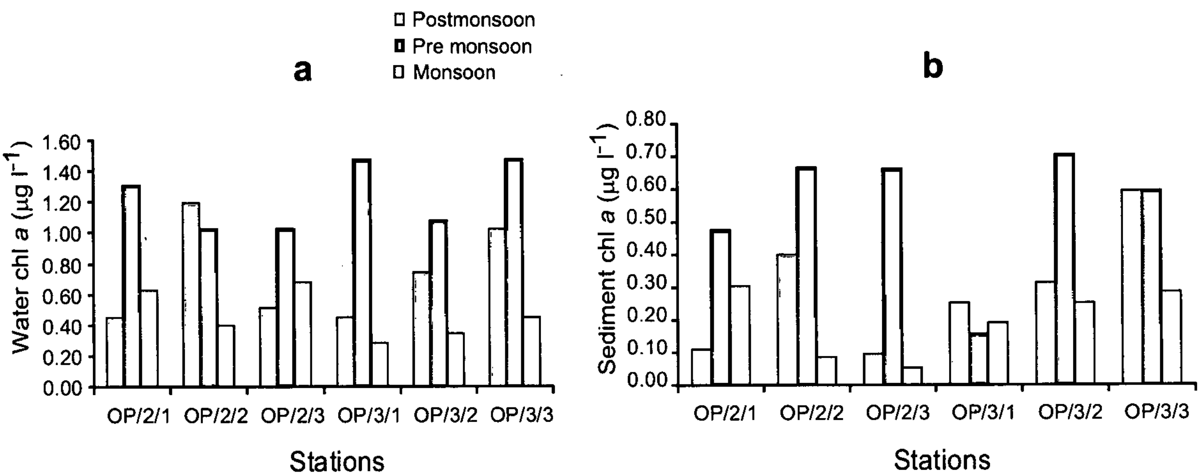


Fig 8.3 Seasonal variation in water (a) and sediment (b) Chl *a* in the study area

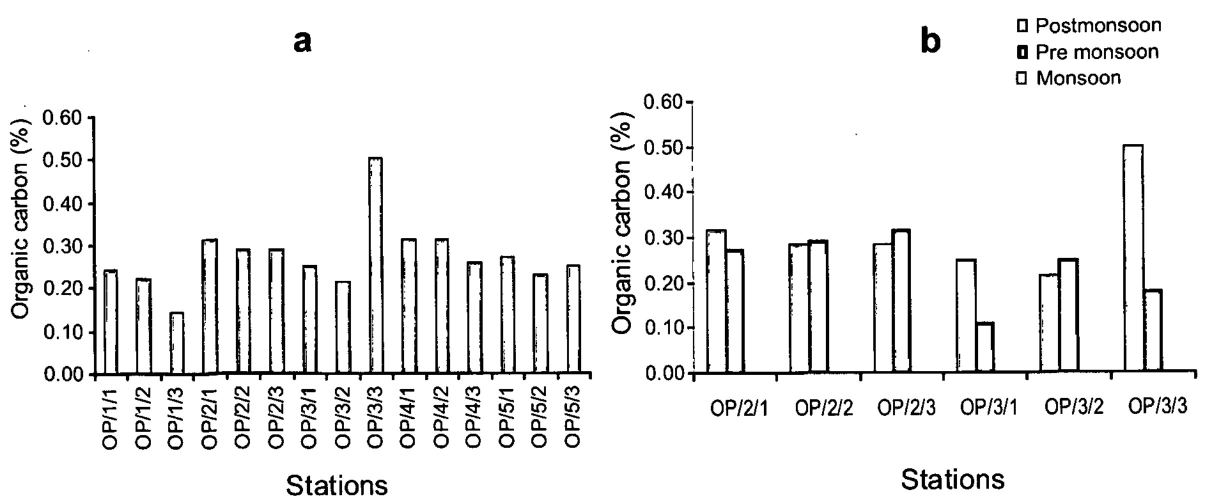


Fig 8.4 Sediment organic carbon at baseline stations (a) and seasonal variation (b)

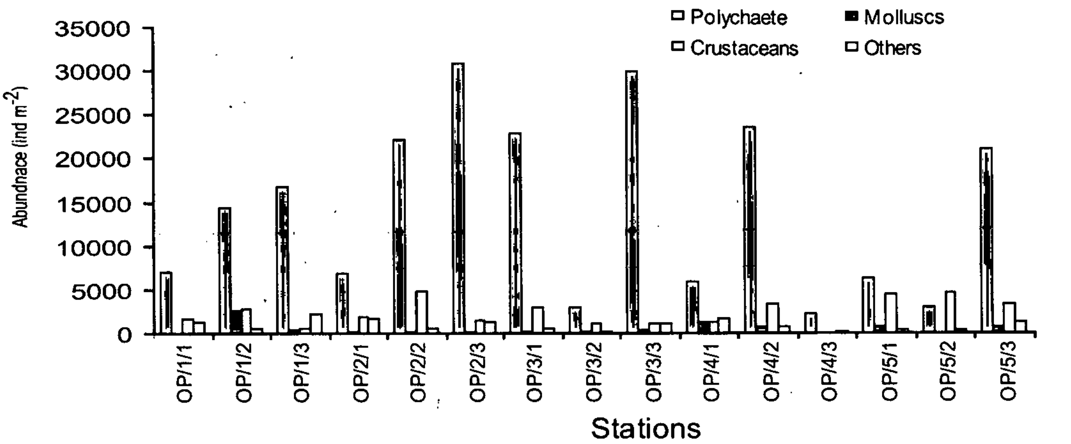
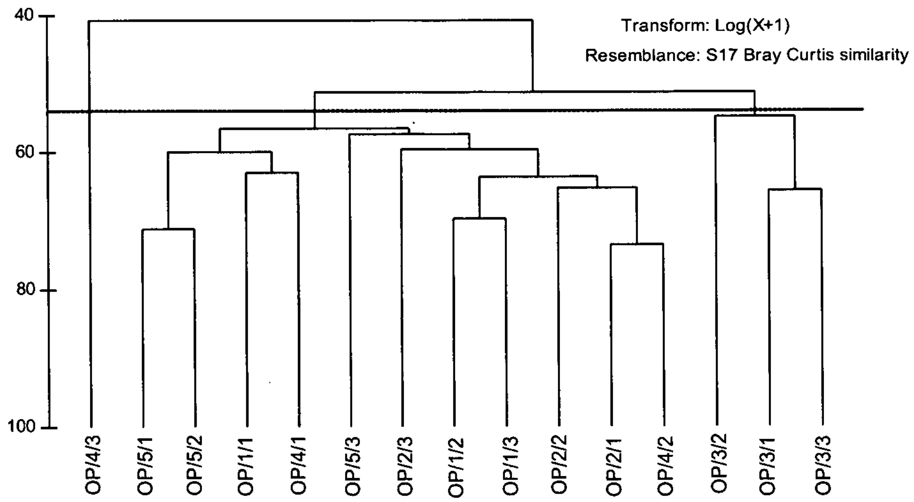


Fig 8.5 Variation in macrofaunal group abundnace at the baseline stations

a



b

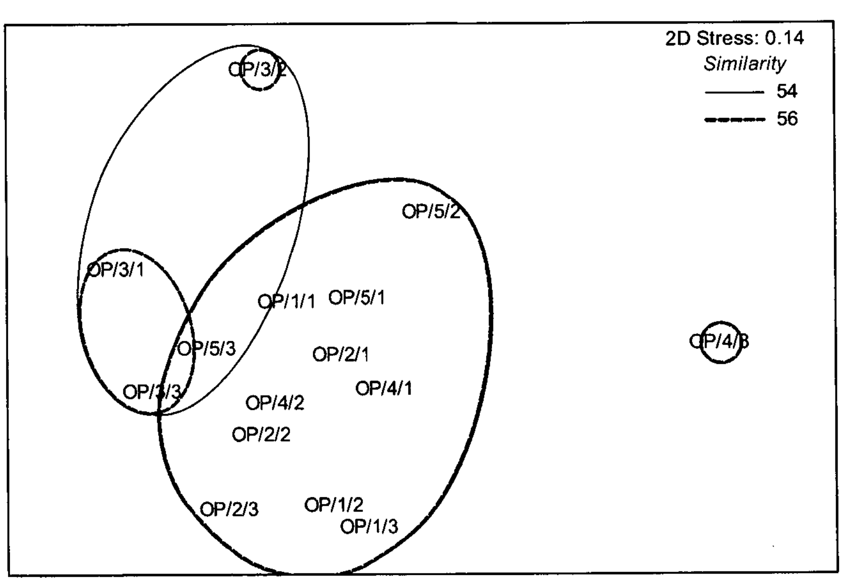


Fig 8.6 Bray Curtis cluster (a) and MDS ordination based on macrofaunal abundance at the baseline stations.

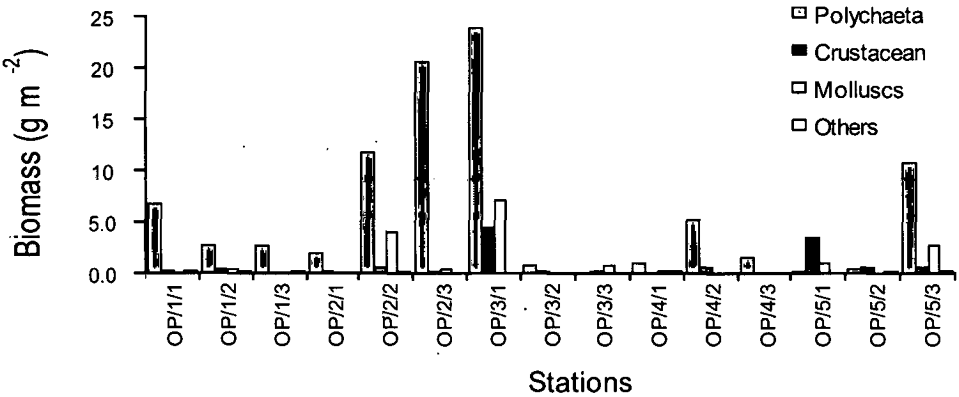


Fig 8.7 Macrofaunal group biomass at the baseline stations

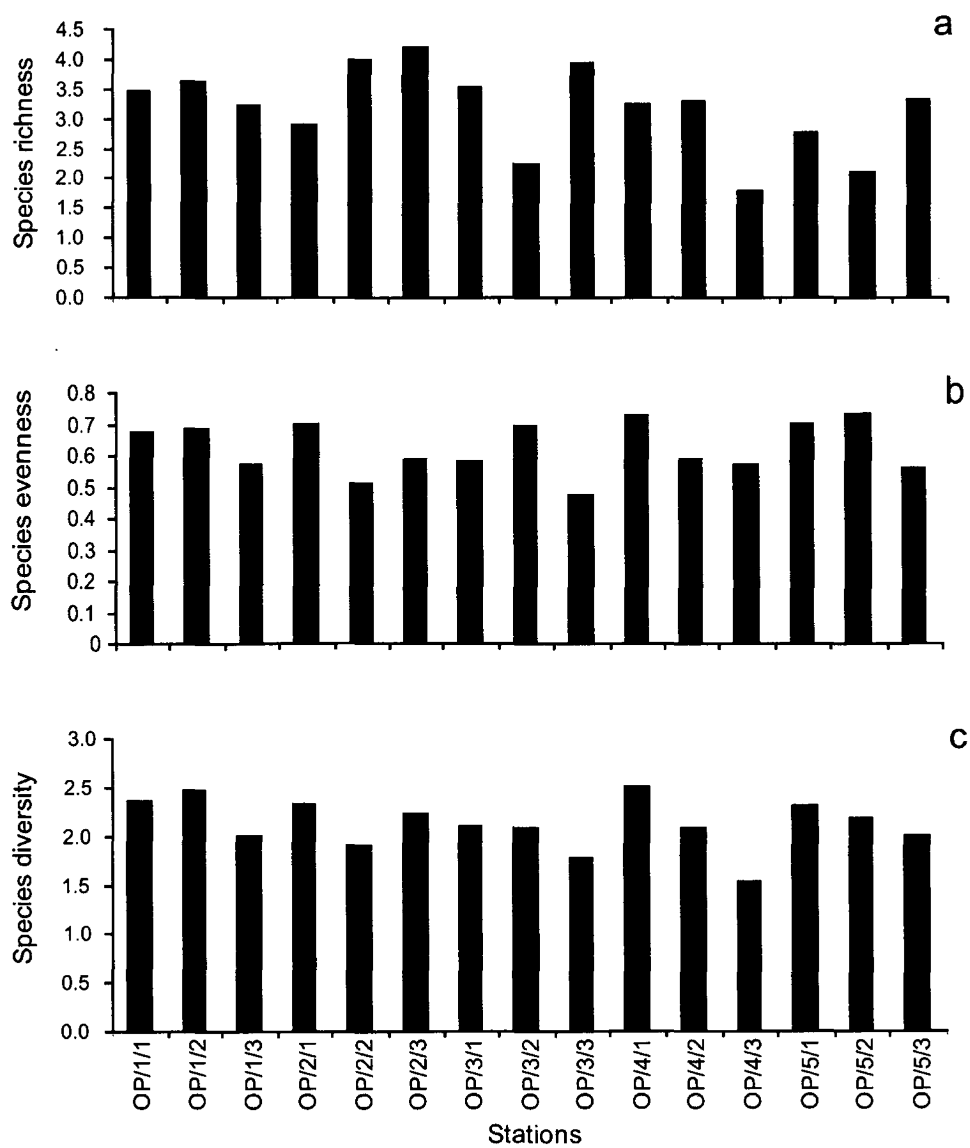


Fig 8.8 Macrofaunal species richness(a), evenness (b) and diversity(c) at baseline stations

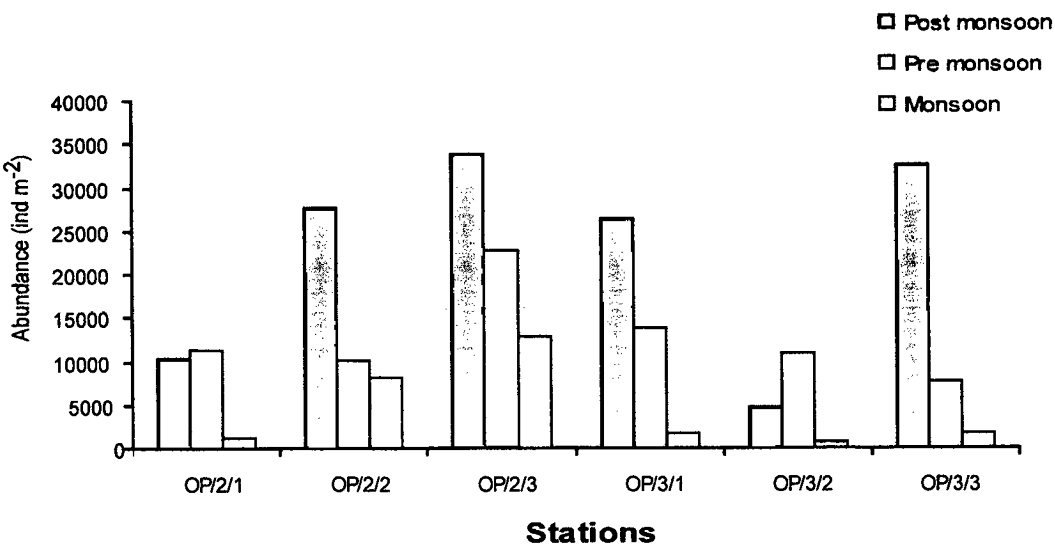
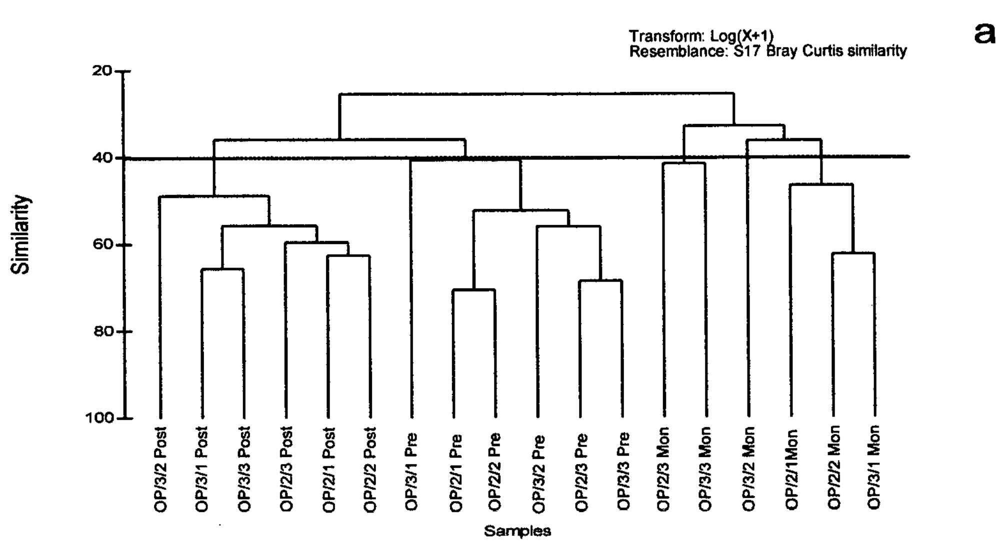


Fig 8.9 Spatio-Temporal variation of macrofaunal abundance



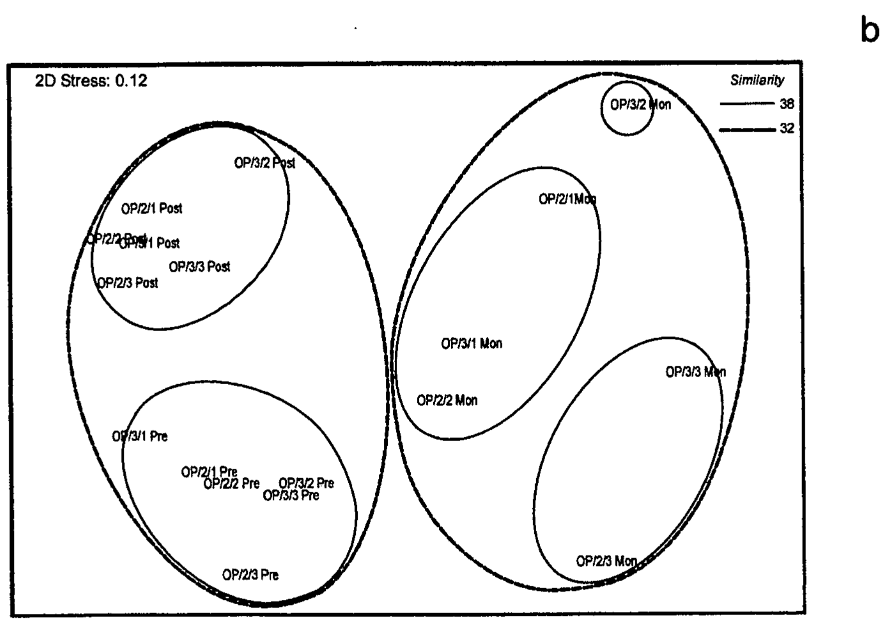


Fig 8.10 Bray Curtis cluster (a) and MDS (b) based on macrofaunal abundance

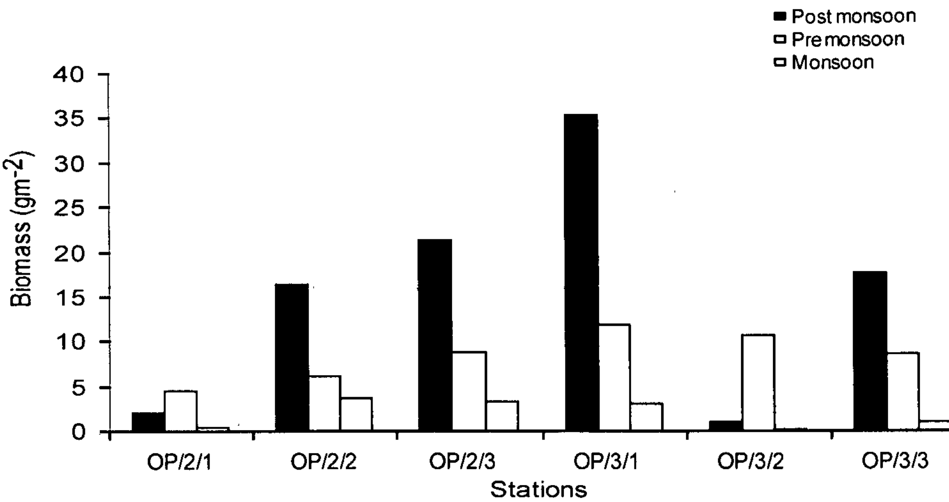


Fig 8.11 Spatio-Temporal variability of macrofaunal biomass

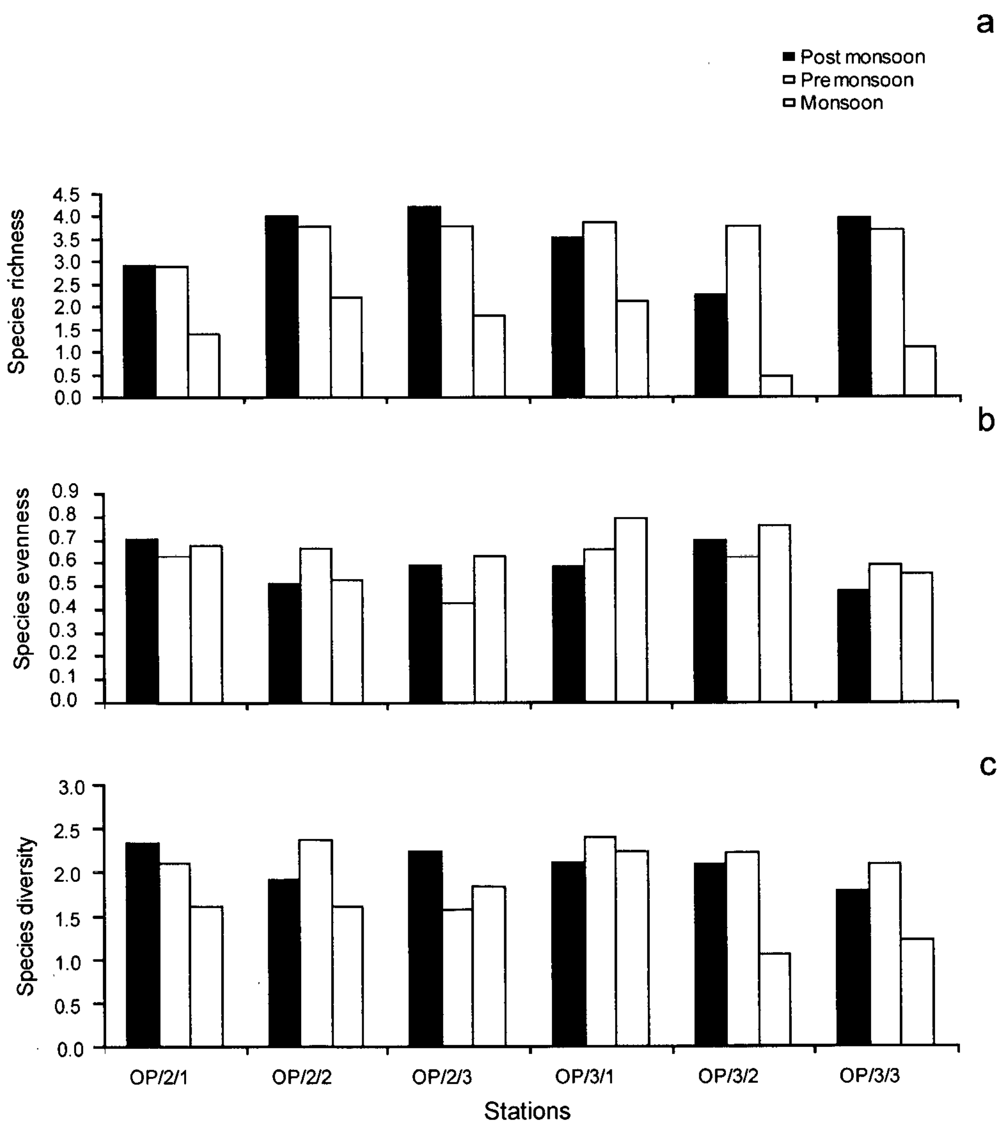


Fig 8.12 Spatio-Temporal variability of species richness(a), evenness(b) and diversity(c)

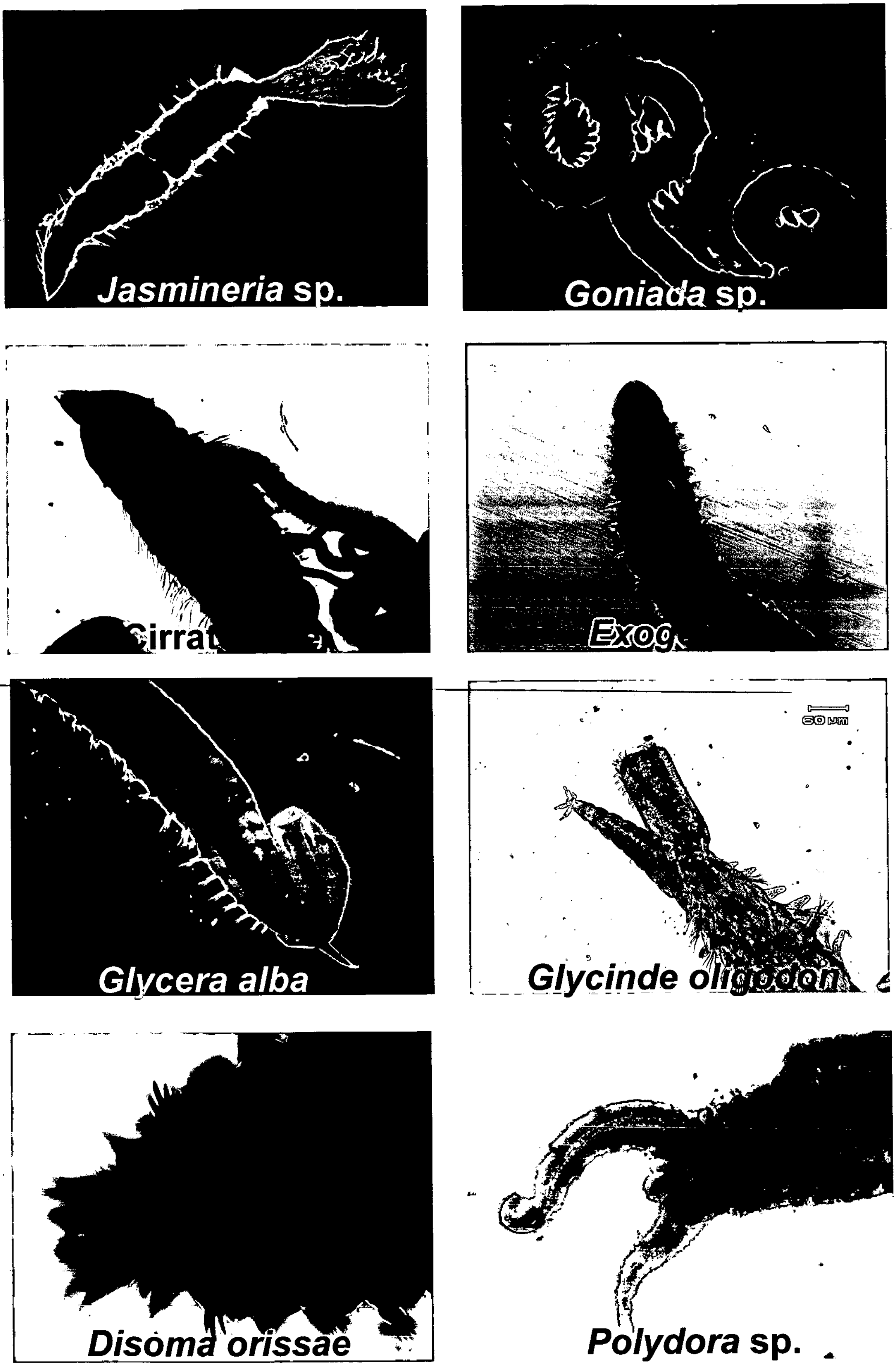


Plate 8.1 Polychaete species from the subtidal region of Kalbadevi Bay

Chapter 9

Impact of simulated mining on the macrofauna

9.1 Introduction

Growing concern about human influence on marine ecosystems conflict with our inability to separate man-made impacts from natural change (Duarte et al. 1992).The coastal system all over the world are continuously stressed by man-made disturbances (offshore construction, dredging and mining activities).

Dredging is carried out in coastal areas to make the waterways navigable. A more recent development is the dredging for resources such as sand and gravel for various purposes. Though dredging is carried out periodically, no study has been carried out to study the impact of dredging and time taken for re-colonization by sediment associated community. Therefore, the assessment of impacts of the activity on the ecology of the surrounding area needs to be investigated in detailed. It includes the physical, chemical and biological characteristics of the ecosystem and their inter-relationships. Such study is particular important because it is now widely accepted that ecosystem functioning is dictated by the biodiversity and community structure. Re-colonisation of the dredged and surrounding area is very much a site-specific process, with both the time scale involved and the resulting community being dependent upon hydrodynamic and sediment condition (Morton 1977; van der Veer et al. 1985).

Although the sandy beaches have been studied for more that 50 years, investigators are reluctant to attempt manipulative experiments due to the dynamic nature of this environment (Schoeman et al. 2000). Consequently, the ecology of sandy beaches remains relatively poorly understood. During the present study an attempt was made to evaluate the impact of physical disturbance on the macrofauna of the intertidal beach of Kalbadevi- a potential placer mining site along the central west coast of India. Although, the impact of anthropogenic activities on the intertidal habitat has been well studied (Olive 1993; Wynberg and Branch 1994; Brown and Wilson 1997; Cotter et al. 1997; Hall and Harding 1997) the same is not the case with manipulative experiments on the dynamic sandy beach.

However, with the increasing importance of Kalbadevi Bay and the potential of the area being mined, experimental study were carried out for understanding the ecology of the area and impact of mining on the benthic community. This chapter presents the results from the impact of simulated mining on the macrobenthic community of the intertidal and subtidal region of Kalbadevi Bay.

9.2 Materials and Methods

9.2.1 Simulated Mining in the Intertidal zone

Disturbance was carried out in the central transect (BP/2; Fig 9.1). A total of five pits (1m x 1mx 1m, Plate 9.1) were made at five locations representing dune, berm, high tide, mid tide and low tide. It was not possible to dig 1m in low tide line because of water percolation. An effort was made to remove black sand sized mineral grains from the excavated part by panning and chaffing and then the remaining materials was put back into the pits in order to simulate the coastal mining. Sampling was carried before, immediately after the disturbance and 24 hrs after disturbance. Monitoring was carried out two months, three and nine months and 1 year after disturbance. Samples were collected using a acrylic core (∅ 12 cm, Plate 9.1f) and processed using standard method as mentioned in chapter 4. Sediment samples were also collected separately for sediment texture, organic carbon and chl a.

All macrofauna samples and environmental parameters were processed following standard methods as described in previous chapters. Data were processed using Primer 6 and Statistica 6.

9.2.2 Simulated Mining in the Subtidal zone

Sampling in the subtidal region was carried out in the central transect (OP/2; Fig 9.1). Sampling was carried out at three stations; stn S was located in the area where the suction was carried out, stn D was in the discharge point where disturbed material was dumped and stn R was the reference station located ≈26 m away from the disturbance area. The loosening of sand was done by series of high-pressure water jet, which was created by high- pressure pump that was installed on the barge (Plate 9.2 a and b). Sediment samples were collected from all the three points before the start of disturbance experiment and after completion of test mining. Monitoring was carried out after two months and second monitoring after eight months of disturbance. Sediment samples were collected using van Veen grab (0.04 m^2). Sediment for macrofauna was collected in duplicates and preserved in 5% neutralized rose-bengal formalin solution. Sediment was collected separately for organic carbon and chlorophyll and stored at low temperature. The samples for macrofauna and environmental parameters were processed using standard methods as described earlier (chapters 2 and 3). Data analysis was processed using Primer 6 and Statistica 6.

9.3Results

9.3.1 Impact of Mining on the intertidal community

The abundance of macro-invertebrates in the disturbed area before the disturbance was 884 ind m^{-2} which was reduced significantly after the disturbance (530 ind m^{-2}). The fauna showed higher abundance in first monitoring (2740 ind m^{-2}; 2 months) and increased thereafter to 5038 ind m^{-2} during second monitoring (3 months; Fig. 9.2a). The abundance was reduced during the fourth monitoring (353 ind m^{-2}). A similar pattern was observed with biomass. The value was considerably reduced from 1.29 g m^{-2} before disturbance to 0.011 g m^{-2} after disturbance, showing a reduction of 99%. Species number also reduced after the disturbance (Fig 9.2 b). Similarly, the evenness reduced after disturbance with lower values during third monitoring (monsoon; Fig. 9.2c). Species diversity reduced from 1.88 to 1.56 and showed decline during the study period (Fig 9.2 d).

The reference station showed similar faunal abundance to the experimental station however, species composition varied distinctively. The abundance of macrofauna showed fluctuation and ranged from 707 ind m^{-2} before disturbance to 6629 ind m^{-2} during the last monitoring sampling. The species number and diversity value showed an increase during first monitoring and decline thereafter. Species diversity was higher during the fourth monitoring (1 year after the experimental disturbance). MDS cluster based on the faunal abundance indicated variability in the study area (Fig. 9.2 e).

9.3.2 Response of subtidal macrofauna to the experimental disturbance

The chl a in surface water ranged from 0.056-0.14µg l^{-1} at stn S. The values in bottom waters ranged from 0.17-0.22µg l^{-1}(Fig. 9.3 a). At stn R, the chl a ranged from 0.11-0.25µg l^{-1} and 0.17- 0.39µg l^{-1} in bottom waters. However, stn D showed a decline in chl *a*. Surface water chl *a* ranged from 0.23-0.11 µg $l^{-1}$and bottom water ranged from 0.17-0.39µg l^{-1}. Surface and bottom water phaeo showed a similar trend as that of chl *a*. At Stn S, the surface water phaeo ranged from 0.22-0.48µg l^{-1} and in bottom waters, the values ranged from 0.56-0.66 μg l^{-1} (Fig. 9.3b). At stn R, the phaeo in surface water varied from 0.34-0.53 μg l^{-1} and 0.55-1.19μg l^{-1} in bottom waters. There was an increase in sediment chl *a* at stn S as well as stn R (Fig.9.3c). The organic carbon increased at stn S and D. At stn S the OC increased from 0.23 to 0.48% and at stn D, it increased from 0.069 to 0.35% (Fig. 9.3 d).

Before the disturbance, the fauna at experimental site was represented by 10 major groups. The abundance at stn. R was 2600 ind m^{-2} and polychaetes was the most dominant group (41.35%). Among the polychaetes, unidentified cirratulides were the most abundant and constituted 10% of the faunal abundance. It was followed by *Eteone* sp. (8.65%). Cumaceans were the second dominant group (22 %), followed by Foraminifera (10.58%). Other groups recorded were Nemertenia, Amphipoda, Tanaidacea and Bivalvia contributing with 9.6%, 8.65%, 8.6% and 2.8 %, respectively to total faunal abundance.

The faunal abundance at stn S before the disturbance was 2700 ind m^{-2} (Fig. 9.4a) and was dominated by crustaceans. Cumacea was the most dominant among crustaceans and contributed to 33.33% of the total faunal abundance. Polychaeta was the second dominant group (28.7%). *Mediomatus* sp. which comprised 7% of total macrofaunal abundance was the most dominant polychaete. *Eteone* sp. was next in the order of dominance (6.0%). Isopoda accounted to 10.65% of the total macrofaunal abundance and was represented *Cyathura* sp. Other groups recorded were Nemertenia (10.18%), Amphipoda (9.72%), Bivalvia (3.24%), Foraminifera (2.31%), Tanaidacea (0.46%) and Ophiuroida (0.46%).

Faunal abundance increased to 3075 ind m^{-2} immediately after disturbance. Polychaeta dominated the abundance with 39.13%. Among the Polychaetes, *Eteone* sp. was the dominant (8.0%) followed by *Mediomatus* sp. (5.6%). Cumacea was second dominant taxa (29.19%) followed by Nemertenia (16.77%). Other groups were Amphipoda, Isopoda, Tanaidacea and Decapoda with abundance of 7.45%, 5.59%, 0.62% and 0.62% respectively. Monitoring, showed a further increase in the abundance in pre monsoon (4425 ind m^{-2}) but the abundance decreased to 2975 ind m^{-2} in monsoon (Fig. 9.4b).

At stn D, the faunal abundance was 3675 no.m^2 before disturbance. Polychaeta was the dominant group with 44.89% of total macrofaunal abundance. Cirratulidae was dominant species with 9.83% of the total macrofauna. *Magelona* sp. contributed to 6.12% and was the second dominant polychaete species, followed by *Eteone* sp (8.52%). Second dominant group was Cumacea, which contributed to 26.53% of total fauna followed by Isopoda (9.52%). Nemertinea, Amphipoda, Bivalvia and Tanaidacea with abundance of 7.48%, 7.48%, 3.40% and 0.68% respectively of total macrofaunal abundance.

After the disturbance, the fauna showed a marginal (3.12%) increase from 3675 to 3813 ind m^{-2} (Fig 9.4a). Polychaeta continued to be the dominant (42.62%) group and unidentified Cirratulidae (9.83%) was the most abundant species, followed by *Eteone* sp. (8.52%) and *Magelona* sp. (6.89%). The second dominant group was Cumacea, (24%) and Nemertinea (14.4%). Other groups were Isopoda, Bivalvia and Foraminifera contributed to 11.80%, 2.3% and 1.6% respectively to the faunal abundance.

The faunal biomass at stn S decreased from 0.25 to 0.15 g.m^{-2} immediately after the disturbance. On contrary, there was substantial increase in biomass from 0.05 to 0.32 g.m^{-2} at stn D (Fig 9.4 c). Species number also increase from 25 to 30 taxa and richness increased from 3 to 3.6 at stn D after disturbance. However, the values reduced during the monitoring phase indicating that the increased at stn D during the experiment was probably due to the dumping of spoilage. It also suggests that the suction head actually accumulated surface fauna which get deposited at the dumping site along with spoilage.

The number of species and richness during the first monitoring were 26 and 2.9 respectively. It showed further decrease to 15 and 1.75 during the second monitoring (Fig.9.4e) Species evenness and Shannon Wiener diversity also showed a similar increase after disturbance. Evenness increased from 0.74 to 0.77 and 2.39 to 2.6 respectively after the disturbance. Evenness value was lower during first monitoring (0.7) and higher during second monitoring (0.78). Species diversity was reduced to 2.3 during the first monitoring. The values were reduced further during the second monitoring (2.1). At the stn D, species number was 18, which increased to 23 after the disturbance. Margalef's species richness increased from 2.07 to 2.67. Evenness showed a decrease from 0.79 to 0.78, whereas diversity increased from 2.3 to 2.5 during monitoring phase (Fig. 9.4 f).

9.5 Discussion

9.5.1 Impact of simulated Mining on the macrofauna

The factors, which control structure and dynamic of communities, are central themes of theoretical and applied ecology. Besides other factors, disturbance plays a key role in various theoretical approaches (Menge and Sutherland 1987). Large-scale physical disturbance are becoming integral element of models, which tries to explain community development and succession (Gray 1997). Experimental manipulations of natural populations in field situations are often the most profitable method of determining the factors, which affect the distribution and abundance of species.

Sediment granulometry did not show much variation after the simulated disturbances in the intertidal region. However, the macrofaunal abundance differed significantly during the study period and was strongly influenced by seasonal variability. The simulated mining was carried out in the mid tide region since the high tide region is usually low in abundance and diversity whereas at the low tide region is always under the influence of tide and hence it would be difficult to interpret the data.

The field experiment was designed to simulate the mining in the intertidal region of Kalbadevi- a potential placer mining site. It was hypothesized that the macro-invertebrates would be affected negatively due to the physical disturbance. However, the entire community had changed in time and space. Faunal abundance in the experimental area (707 ind m^{-2}) and reference area (884 ind m^{-2}) was comparable before the manipulation experiment. The species number and diversity increased in the experiment area immediately after the disturbance. However, the monitoring carried out 24 hr of disturbance showed ≈40% reduction in the faunal abundance, 28% reduction in species richness and species diversity was reduced by 17% in the experimental area. Though, the reduction in the abundance of reference area was comparable (49%) to the disturbed site, the species richness and diversity was increased at the experiment site. The polychaete communities were the dominant in the experiment area before the disturbance was reduced by 67% in the abundance and 50% in species number. The reference area before the disturbance was dominated by the crustaceans (unidentified amphipod and *Eurydice* sp.) and bivalves (*Donax* sp.). Some of the species showed horizontal as well as vertical movement. The polychaetes are sedentary in nature; and hence the reduction in their abundance was as expected due to the experimental disturbance. On the other hand, the abundance of fast moving *Donax* sp. was increased after disturbance.

Closer scrutiny of the biotic and abiotic parameters of both the reference and experimental area revealed significant seasonal variation. It implies that observed variation in the biotic parameters does not necessarily signify the effects of simulated mining. MDS analysis ordination also reflected spatio-temporal variability (Fig. 9.2 e). Significant clustering was observed between reference station and experimental stations of second monitoring. Overall, the analysis indicated high degree of dissimilarity amongst the samples. The MDS ordination also reflects the general dissimilarity of samples and the relatively low stress of 0.04 indicates consistency of results. Consequently, the multivariate analyses confirmed the findings of the univariate parameters.

One of the major factors influencing the spatio-temporal variability of the biotic parameters was the beach gradient which was a natural response of physical environment (McLachlan et al. 1993). Beach gradient has been routinely used to predict patterns in macrobenthic community. The sediment texture showed temporal variation and thus the variability in the macrobenthic community between the sites may be influenced by the physical environment and hence confounded the results of the present study.

The observed natural variability was unpredictable and beyond the control, epitomizing the spirit of Hulbert (1984) of 'demonic intrusion". Although the inability to isolate the natural variability from manipulative disturbance, it does not invalidate the present results, but it does make the interpretation problematic. Since the exposed sandy beaches are highly dynamic system, which is likely to hamper such manipulative experiment until experiment treatments are replicated in space and time, however an expensive solution. Further, the area was very well studied with extensive sampling. The macrofaunal community displayed a significant spatio-temporal variability along the entire 5 km stretch of the beach. As a result locating a reference station with identical macrobenthic community as the experimental site would be difficult.

Although it could be argued that the decline in abundance at the experimental site were natural, since similar decline was also observed at the reference site, there are evidence to suggest otherwise. Along with the decline of macrofaunal abundance, species richness and diversity showed a decline at experimental site which was not observed at the reference site. Further, the macrofaunal abundance that accounted for the decline was in sedentary polychaetes. In fact the mobile fauna was the only community remained at the experimental site after disturbance. However, the mobile fauna may have been migrated from the adjacent area with moving tides. A similar experimental disturbance carried out by Schoeman et al (2000) concluded that *Donax serra,* is a poor horizontal locomotors and require assistance of wave and tide for relocalization. Thus, it can be interpreted that the experimental disturbance may have caused the reduction of macrofaunal community in the experiment site.

Despite the dynamic nature of sandy beaches, it may take several days to equilibrate when environmental conditions changes (Schoeman et al. 2000). Further, the sediment that fills the excavated pits may not have been sufficiently compacted to withstand later erosion. Subsequent monitoring suggested that the population abundance and biomass was restored within 2 months of disturbance. It also suggests that intertidal infaunal communities return to pre-disturbance status in <1 year. It agrees with the findings of Sardá et al (2000) who concluded that the faunal restoration in sand extraction site western Mediterranean takes almost one year. The number of species in the disturbed zone also recovered rapidly and density of most of the species was higher than the pre-disturbed values. However, some species such as *N. cirratulus* and *Levinsenia* sp. showed reduction in density indicating that they may require more than 2 months period for the to return to pre-disturbed compositions.

Following anthropogenic impact on the benthos, recolonization will depend upon numerous factors such as stability to disturbed areas, changes in local oceanographic regimes, tolerances of organisms to physical changes and the availability of recruits (Poiner and Kennedy 1984; Hall et al. 1994). Macrobenthic recruitment at Kalbadevi takes place during the post monsoon (Chapter 8). Therefore, long-term study could be required to get a clear idea of recolonization.

Nonetheless, observed fast recovery of some species could be due to the dynamic nature of the intertidal zone. In environments with high levels of disturbances, a large proportion of the habitat will be at some point on a successional trajectory (Hall et al. 1994). In dynamic environments like Kalbadevi beach, the macrofaunal community is represented by a high proportion of mobile species that are capable of rapid recovery following episodic disturbance. The fauna in May (post-disturbance) was dominated by amphipod *Urothoe* sp. and bivalve *Donax* sp. Both these species are mobile which can help them to avoid the disturbance as well as faster recolonization. In contrast, macrofaunal communities in more stable environments comprise a higher proportion of slow-growing 'equilibrium' species that may take significantly longer time to recover (van Dalfsen et al. 2000).

Compared to sandy intertidal beaches, experimental studies have been focused on more stable intertidal zone like rocky shore and mudflats. Disturbance ranged from the scale for relatively small treatments (<1-2.5 m^2) to large areas (3500 m^2) using tractor-hauled dredger (Kim and de Wreede 1996; Cotter et al. 1997; Hall and Harding 1997). By these standards, our manual disturbance of 1x1x1 m^2 was substantial. Aim of the study was to mimic disturbance during mining activities with minimum effect on the environment. From the experimental point, the study was quite successful as reduction was observed in the species diversity after 24 hr.

Prediction of impact on biotic communities remains central to the assessment of potential anthropogenic disturbance, like placer mining. The results of our study suggest that simulated experimental mining on the sandy beach result in detectable impact on the macrobenthic community, but these would be rapidly ameliorated. By contrast, the actual mining would be on large scale and longer duration, which certainly affect the benthic assemblages in the long-term.

Although, research has progressed in the last few decades, including the more stable intertidal rocky and mud flat habitats, very little is known of the sandy beaches. One reason to this was, since the sandy beaches were considered to be "biological desert" and little commercial interest (Papageorgiou et al. 2006). With increasing knowledge of the sandy beach ecosystem and discovery of placer mineral deposits, the need to develop different research approaches of this biological and commercially important ecosystem has become critical. Present results demonstrated that carrying manipulative experiment on this dynamic ecosystem is possible with relevant results. Furthermore, if sufficient resources and time is available to carry the study on larger scales/ replicated, it may be easy for interpretation of influence of natural and anthropogenic disturbance. Such studies on the sandy beach facilitate a better understanding of the beach ecology, once considered to be barren and no commercial importance.

The impacts of mining on the benthic community are expected due to physical removal of burrow material and infauna. Since the disturbances was on a small-scale, the disturbed site did not show much variation in the sediment granulometry, or result in hypoxia or anoxic conditions which may have resulted in the fast recovery of the macrofaunal community. However, the nature and duration of benthic effects may differ with location of mined sites, due to physical and biological differences. Since the study area is also the feeding ground of the marine avifaunal groups especially the sea gulls. Thus, any alteration in their feeding habitat may threaten the very survival of these species. The intertidal habitat of Kalbadevi provides a vital ecosystem in the form of commercial, recreational, and subsistence harvest of fishes. The local people in the area collect *Umbonium* for consumption and also small-scale fishing such as cast net and gill net fishing is carried out on regular basis. Further, the area is located in close vicinity of historically famous "Ganapati Pule Temple" and has vast potential for ecotourism. Thus, the proposed mining operation in the intertidal and subtidal area could cause an adverse impact on the environment and fishing communities in general.

9.5.2 Impact of Simulated Mining

Sedimentary organic carbon showed substantial increase at stn S (68%) and stn D (83%) after the disturbance (Fig.9.2d). It is postulated that this increase was mainly due the shifting of organic-rich deeper sediments to the surface. While discussing the impact of deep sea disturbance on meio- and macrobenthic fauna Ingole et al. (2005 a & b) suggested that disturbance at sea actually enhances the food supply to the benthic organisms by altering the sediment layers which is much similar to the large-scale bioturbation process. According to Bluhm (1994) physical disturbance at deep sea increases the food resources for larger benthic animals by exposing the organic-rich sediment and sediment dwelling organisms to the surface.

Marginal increase in sediment chl *a* was observed at suction point (stn S) when compared with the baseline data (Fig. 9.3a). On contrary, there was 53% reduction at stn D but the reference area did not show any notable change. Considerable decrease at discharge site (stn. D) was due to the increased turbidity. The total suspended matter (TSM) was higher during the disturbance with values as high as 41 mg l^{-1} was observed at discharge site. TSM ranged from 0.7-10.62 mg l^{-1}. Dredging generally increase the TSM (Anon, 2007). Since the phytoplankton is the only source of chl *a* in the water, the role of light intensity is very significant in determining the chl *a* content despite of some other limiting factor, such as nutrient and suspended matter (Strickland and Parsons, 1968). Thus, increased turbidity will affect the amount of light penetrating into the water column (Russell-Hunter 1970). Poor transparency of the water caused by increase in turbidity could have hampered photosynthesis process, which in turn affects the chlorophyll formation in the phytoplankton. According to Pillay (1992) turbidity and availability of light, as well as current and flushing time affects the utilization of nutrients by phytoplankton. High turbidity of the water is known to adversely affect the photosynthesis process.

The total abundance of macrofauna at stn S showed 14% increase immediately after the disturbance. The fauna was dominated by burrowing forms like Nemertean, *Nephtys* sp. *Jasmineria* sp. and *Arcidea* sp after disturbance. Thus, disturbances could have destabilized the sediment exposing the burrowing and tube dwelling organisms to sediment surface which resulted in increased abundance. Also the pressure of hydraulic pump could accumulate the fauna from the adjacent area to the suction head. However, biomass and species number showed significant ($p<0.05$) decreased after the disturbance.

Likewise, abundance (4%) and biomass (74%) was increased at the disposal point (stn D) after the disturbances. It was evident from the faunal composition that increased biomass was largely due to the presence of large sized bivalves that were exposed to surface sediment after the disturbance at stn D. Species number also showed 28% increase after disturbance. Since the suction and disposal sites were in close vicinity, the sediment deposited to the discharge site from the suction was largely responsible for the increased abundance, biomass and species at discharge point after disturbance.

The initial increase in polychaete abundance was due to the increase of burrowing and tube building polychaetes like *Nephtys* sp., *Aricidea* sp., *Jasmineira* sp suggesting that increased abundance immediately after the disturbance was a temporary phase caused by human interference. It supports the early notion that one time sediment disturbance actually help in increasing the faunal standing stock (Ingole 2004; Ingole et al. 2005). However, the increase could be a temporary as the exposed organisms will become more susceptible to predation, leading to subsequent decrease once the habitat is stabilized. The decrease in polychaetes immediately after disturbance was largely attributed to heavy sedimentation (Tkatchenko and Radziejewska 1998) and exposure of the burrowing fauna to predators (Billett et al. 2001). Therefore, the initial increase observed could be due exposure of deeper organism and movement of the organism from the adjacent areas (Ingole et al. 2001). However, species number and biomass showed a decrease indicating the negative impact of simulated mining on the macrobenthic community.

The faunal abundance further increase during the monitoring phase (pre monsoon). However the faunal abundance decreased in monsoon responding to the physical changes (Pannikar 1967). Therefore, the recovery of the benthic community after physical disturbances will depend on various environmental factors. It is generally accepted that the infaunal communities of dynamic sandy habitats recover from physical disturbances more rapidly than those from depositional, muddy sediments (Schratzberger and Warwick 1999; Ferns et al. 2000). In the Baltic Sea, evidences suggest that infilling of the troughs from trailer suction dredging took at least 12 months. This is achieved partly by slumping from the sides and partly by fine material by bottom current into the sediment traps formed by the dredged furrows (Kaplan et al. 1975; van der Veer et al. 1985; Gajewski and Uscinowicz 1993). The natural faunal variability of was superimposed on the simulated mining and hence it was difficult to demarcate the difference between the natural and experimental disturbance effect.

The impact of physical disturbance on the macrobenthic community will be seen, if the dredging brings about change in the granulometry of the site (van der Veer et al. 1985). The original sand and gravel may be replaced by fine sand Desprez (1995) but depends upon the intensity and duration of the disturbance. In the case of experimental furrows dredged by trailer suction in gravel deposits of the southern North Sea off the Suffolk coast of England, even shallow depressions of only 20-30 cm depth were still visible on side-scan sonar records made up to 4 yr later (Millner et al. 1977). The disturbed tracks were visible even after a duration of 44 months in the Central Indian Ocean (Ingole et al *in press*) In contrast, dredge furrows in the Bristol Channel have been reported to disappear within 2 to 3 tides because of high sediment mobility (Newell et al. 2003). In general, dredged tracks will persist for varying times depending on the rate of local sediment fluxes, suggesting 1-4 days only for the Norflolk Bank, but periods as long as 1-4 yr for more stable deposits off the Owers to the east of the Isle of Wight (Newell et al. 2003) and central Indian ocean (Ingole et al. *in press*)

Thus, mining or any physical disturbances will have an important potential impact on the biology of the areas. This will lead to patchy distribution of organisms, reflecting the differences between the disturbed site and the undisturbed surfaces. Recolonisation that will occur is likely to be by migration of adults through transport on tidal currents by transport in sediments slumping from the sides of the pits and furrows; by the return of some undamaged suspended components and by colonization and subsequent growth of larvae from neighboring populations.

The pattern of recolonisation of benthic species of the area is of interest for the prediction of long -term effects on benthic population of the area. In areas with continuous disturbance (such as harbours), the community is replaced and dominated by opportunistic benthic species, especially the polychaetes. It is very well recognized that opportunistic species generally dominate in heavily disturbed areas, probably due to better adaptive strategies (Gray 1979). The Kalbadevi Bay was dominated by macrofauna with wide feeding types. Physical disturbance will generally increase the TSM in the water column, as seen during the present experiment, which can affect the filter feeding species. Also increased turbidity can affect the primary productivity of the area. It can also affect the OC in the sediment. Therefore, if the areas are physical disturbed, then the change in community with dominance of deposit feeders can be expected.

9.6 Conclusion

Placer mining involves the removal of top sediment layer. Since the majority of the benthic fauna are also concentrated in the upper sediment layer, the obvious biological effect of sand mining would be the removal of resident benthic fauna within the mined area. However, the effect of the mining activity will not only be restricted to sediment associated community, but it will also affect other predatory organisms that rely on the benthic organisms for their forage.

Recognizing the environmental effects of mining operations in many instances is similar for most areas. Therefore, the results of the present experimental study can be utilized to examine the effects of particular types of mining operations on the environments. It can also help to develop or recommend appropriate mitigation, computer simulation and modeling or monitoring techniques to alleviate or present adverse environmental impacts. However, while doing this, enough care is required to conserve the residential flora and fauna of the proposed mining area (Plate 9.3).

Following are some of the proposed mitigations measures that can be implemented for the sustainable management of the placer area:

- Mitigations targets aim for rapid recovery of biodiversity. This can be achieved through minimizing impact by planning contiguous mining blocks. As recovery of seabed biodiversity results from larval recolonisation from great distances up to several hundred of kilometers.
- The dredged spoil can be discharged within a small area (identified by detailed study) as possible and close to the mined area so as to minimize the extent of turbidity.
- A monitoring programme to determine whether the mitigation targets are being achieved is extremely important. This must be done in sufficient time pre-operationally so as to allow the sampling stations to be operated before and after mining has begun. Such monitoring will in turn provide a feedback to the miners to know whether and how process adjustment may be made to meet the environmental quality requirement. It will also help the policy makers to assess weather the environmental mitigations are truly implemented or not.

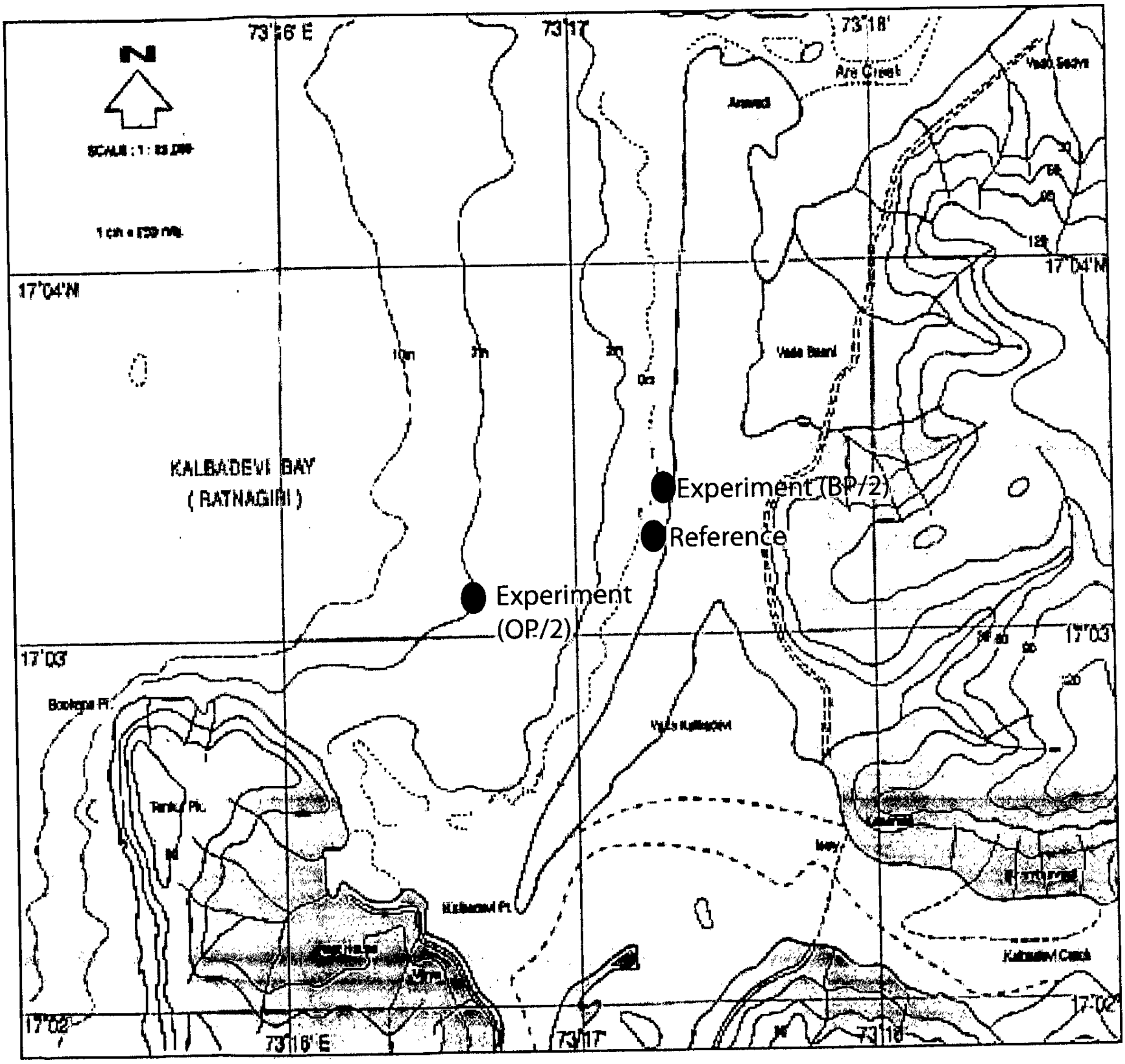


Fig. 9.1 Map showing location of disturbed stations in the intertidal (BP/2) and subtidal region (OP/2).

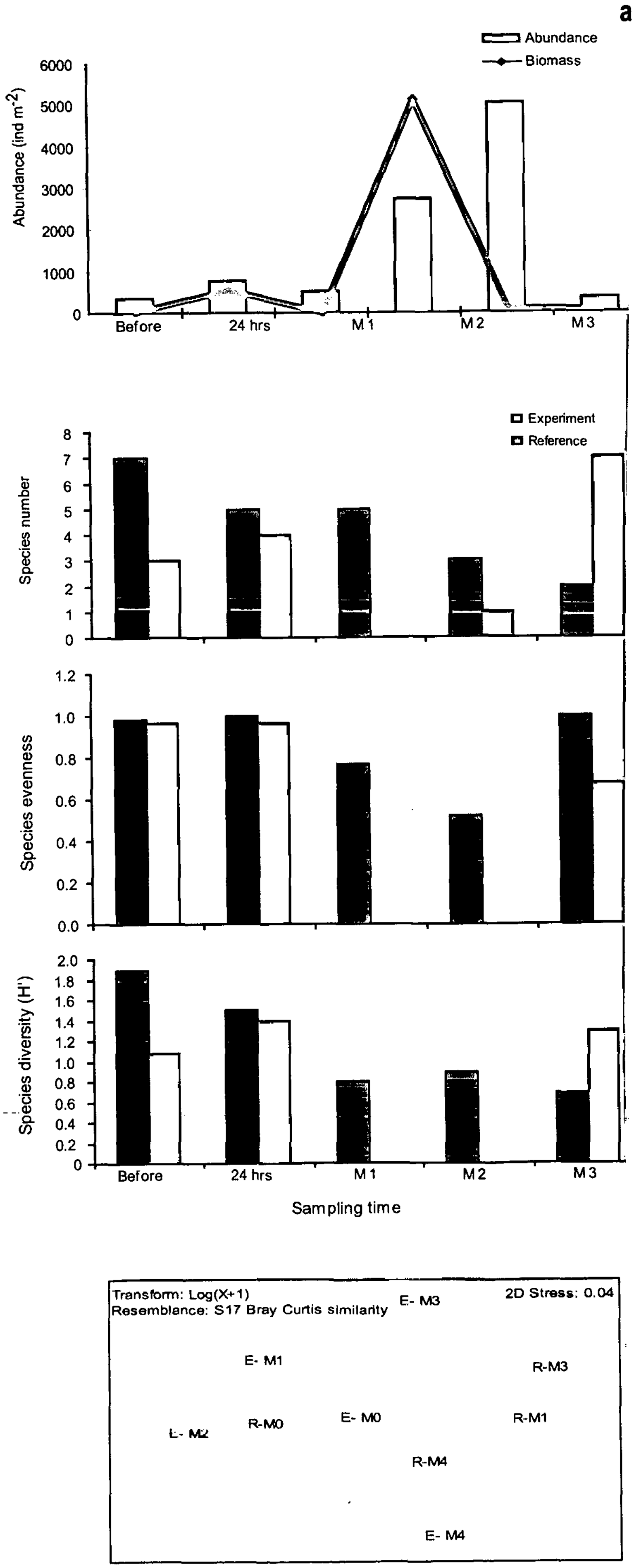


Fig 9.2 Variation in macrobenthic parameters and MDS based on ma
in the experimental transect.

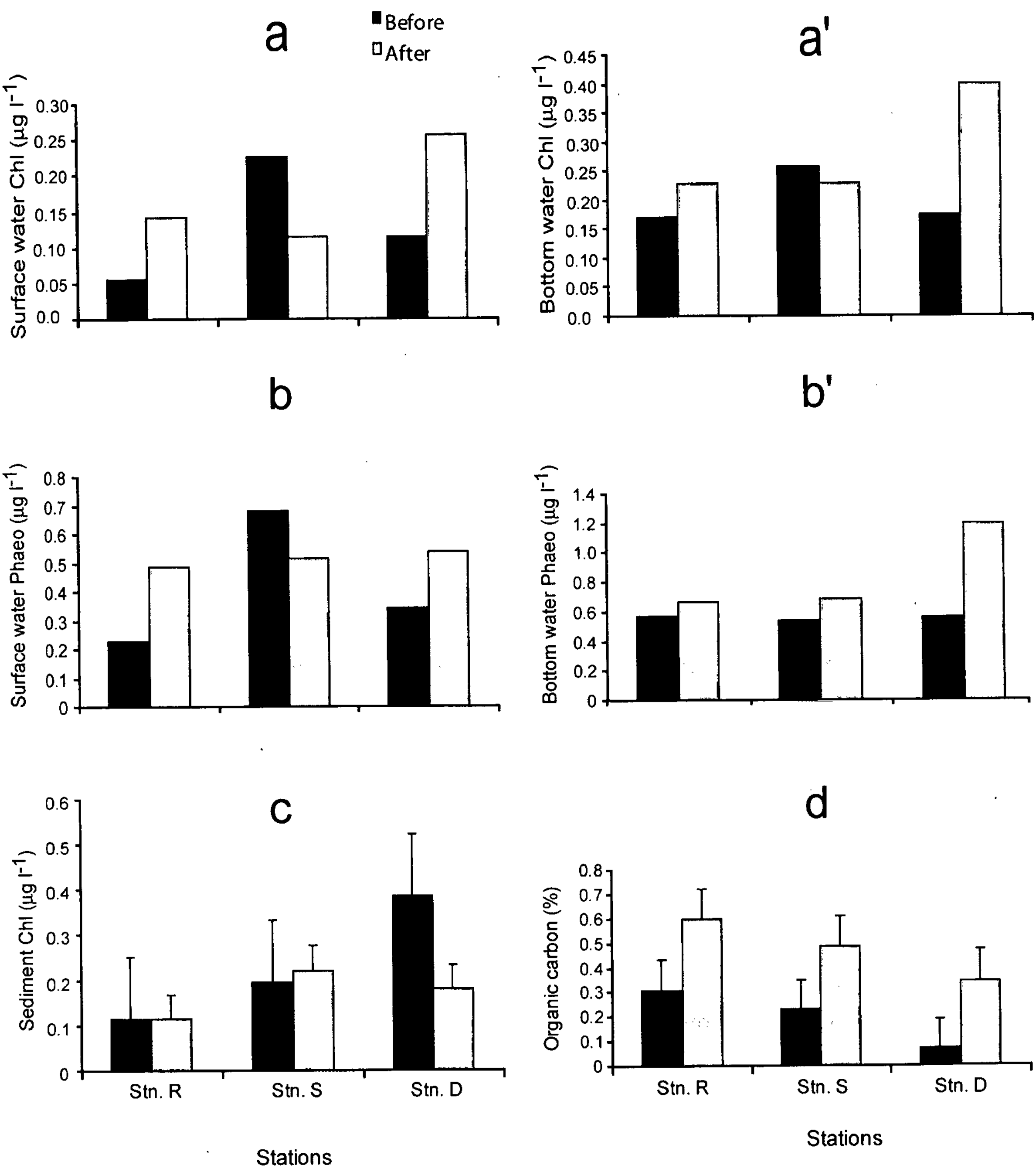


Fig 9.3 Variation in water chl (a), water phaeopigment (b), sediment chl (c) and OC(d)

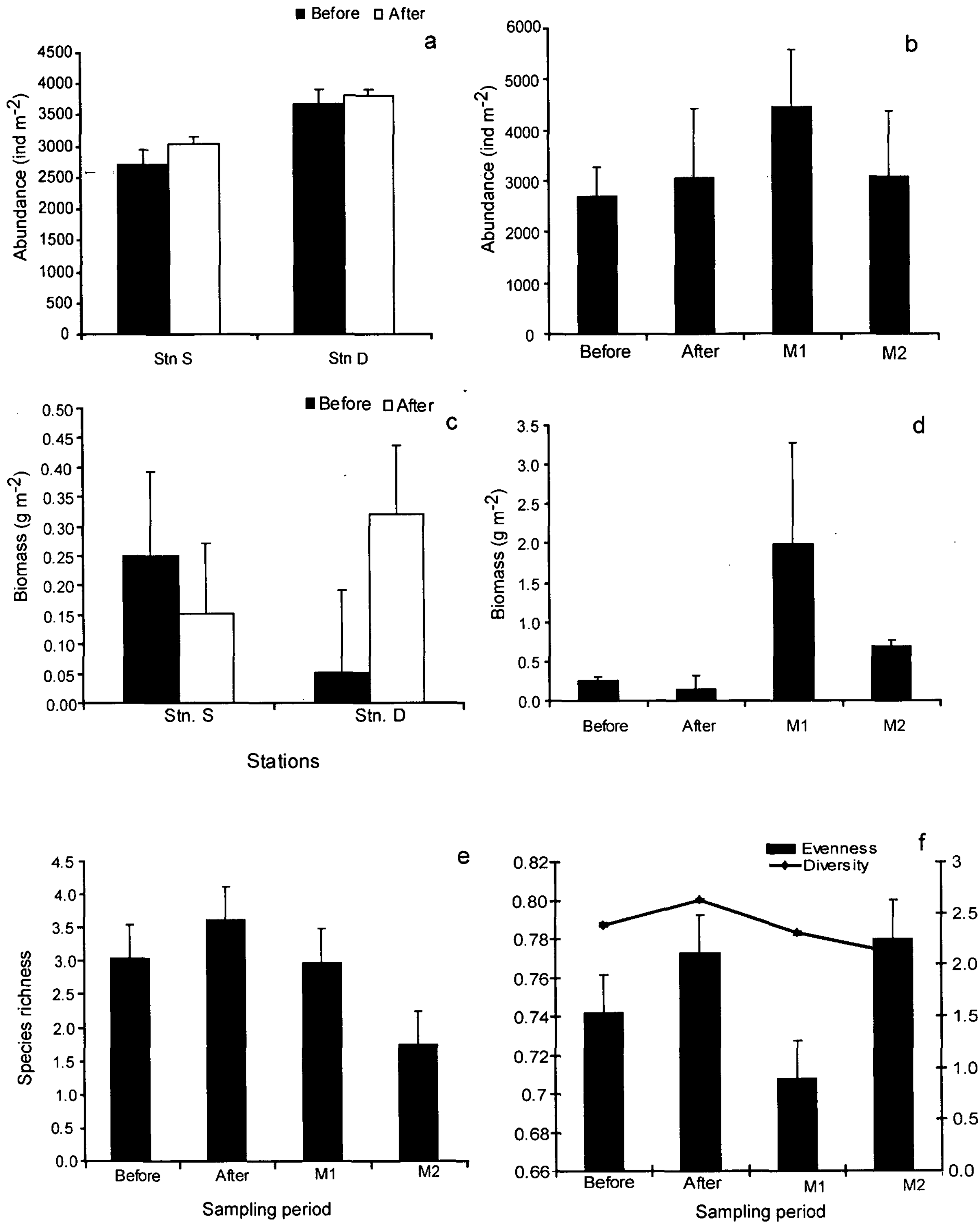


Fig 9.4 Variation in subtidal macrofaunal abundance during experiment (a) and monitoring period Stn S. Biomas during experiment(c) and during monitroing at stn S. Species richness (e) and Species evenness and diversity (f) at Stn S. (M1-first monitroing; M2 - second monitroing

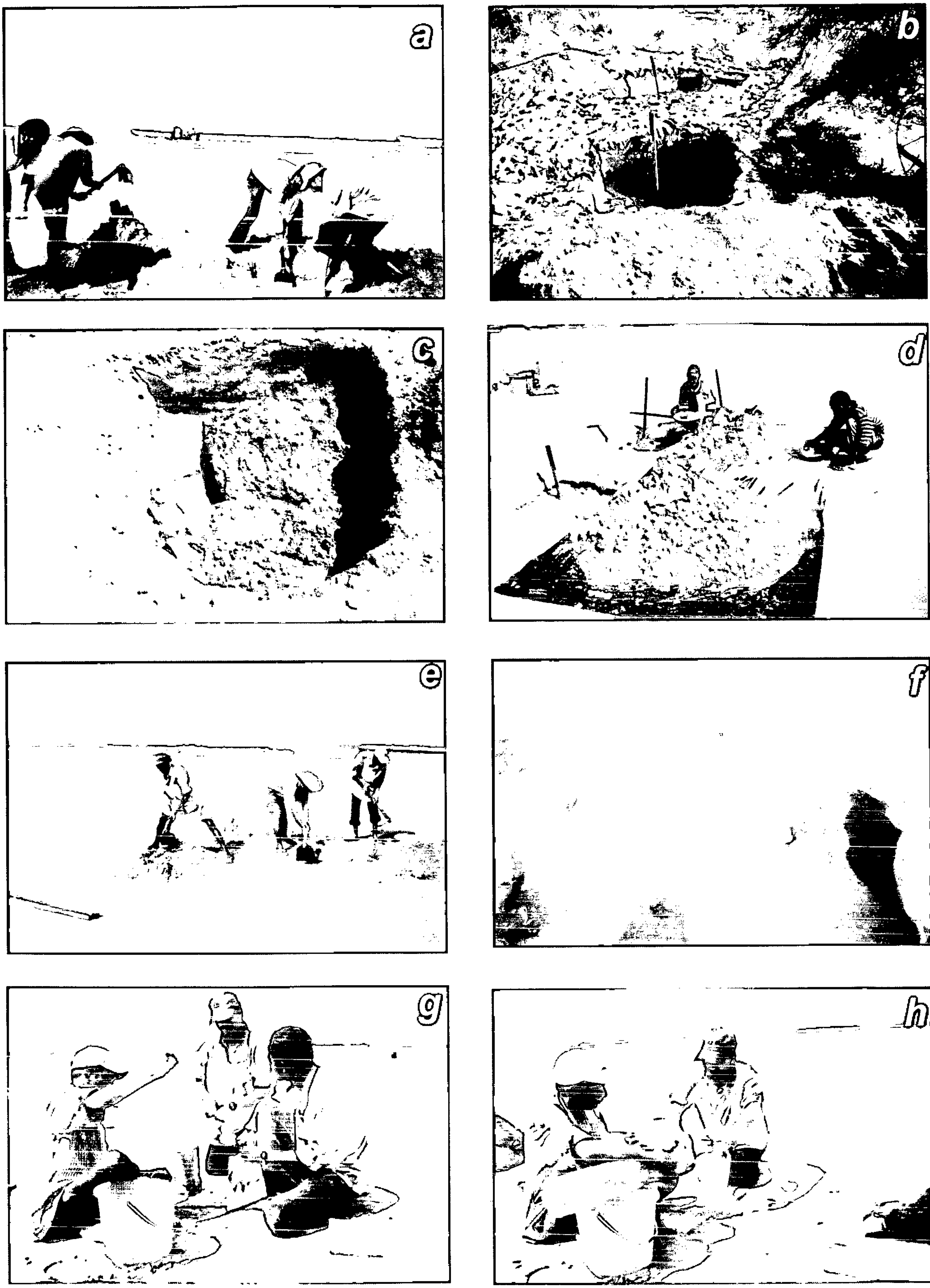


Plate 9.1 Simulated mining experiment (a-e) and sampling (f-h) in the intertidal region of Kalbadevi Bay

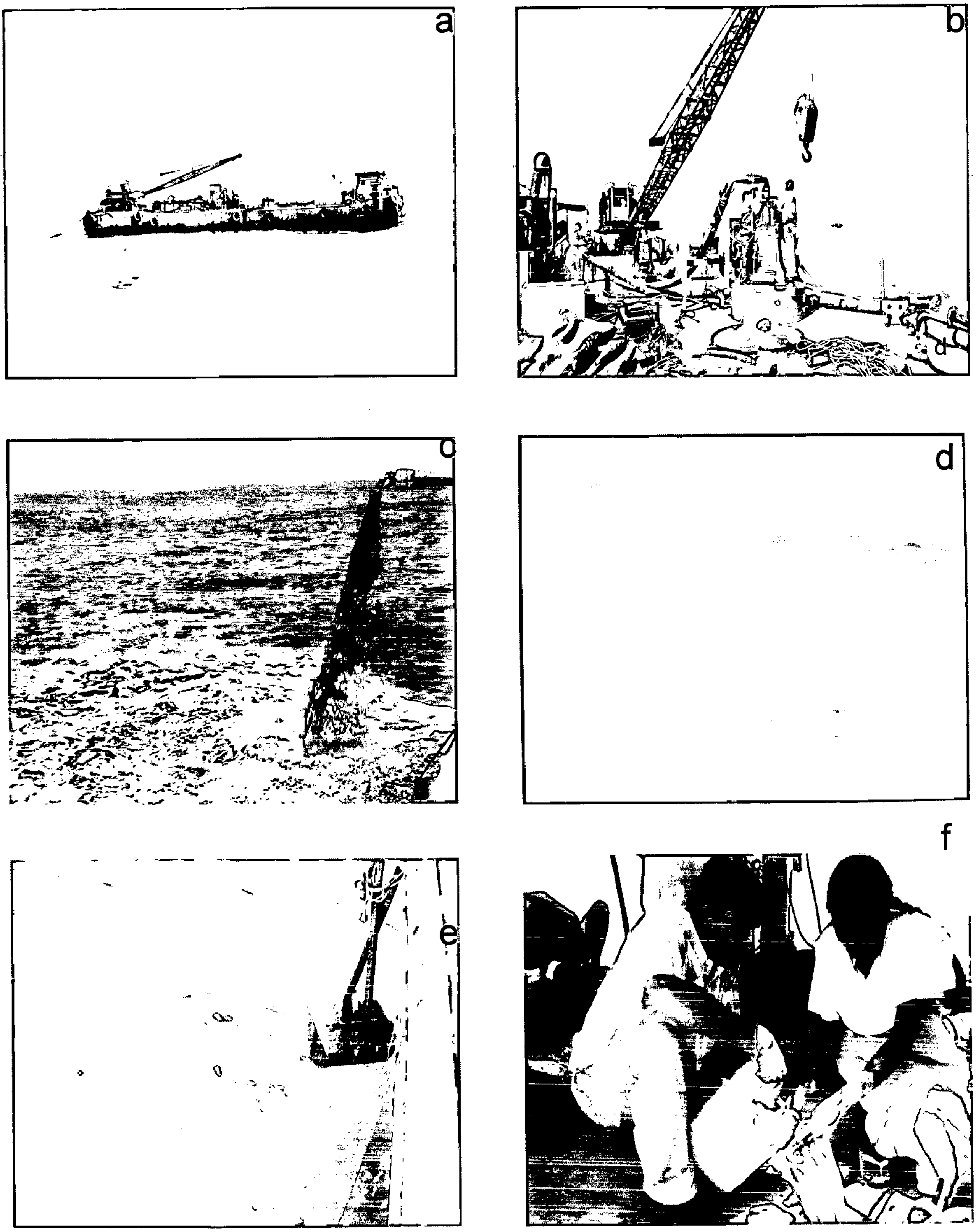
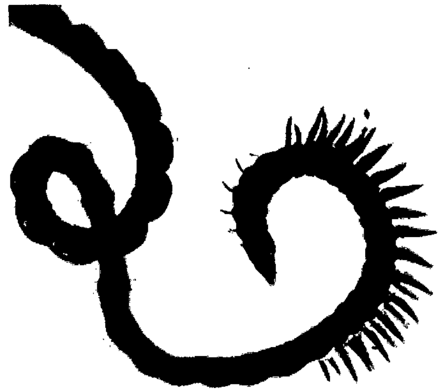


Plate 9.2 Simulated mining experiment in the subtidal region. Pantoon (a), suction pump (b) discharge point (c-d), van veen grab (e) and preservation of macrofauna (f)

Plate 9.3

Polychaetes of West Coast of India

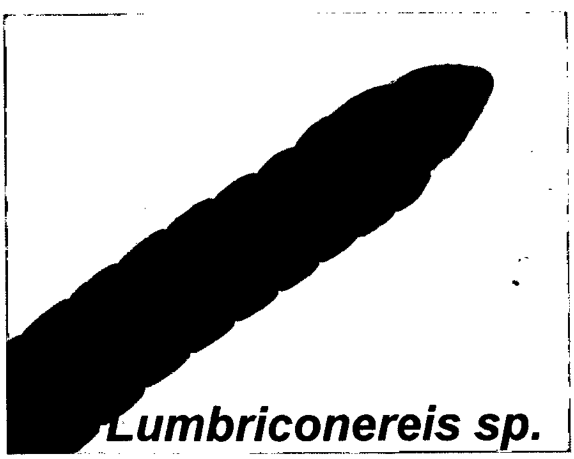
Aricidae catherinae



Levinsenia sp.

Pisione oesterdii

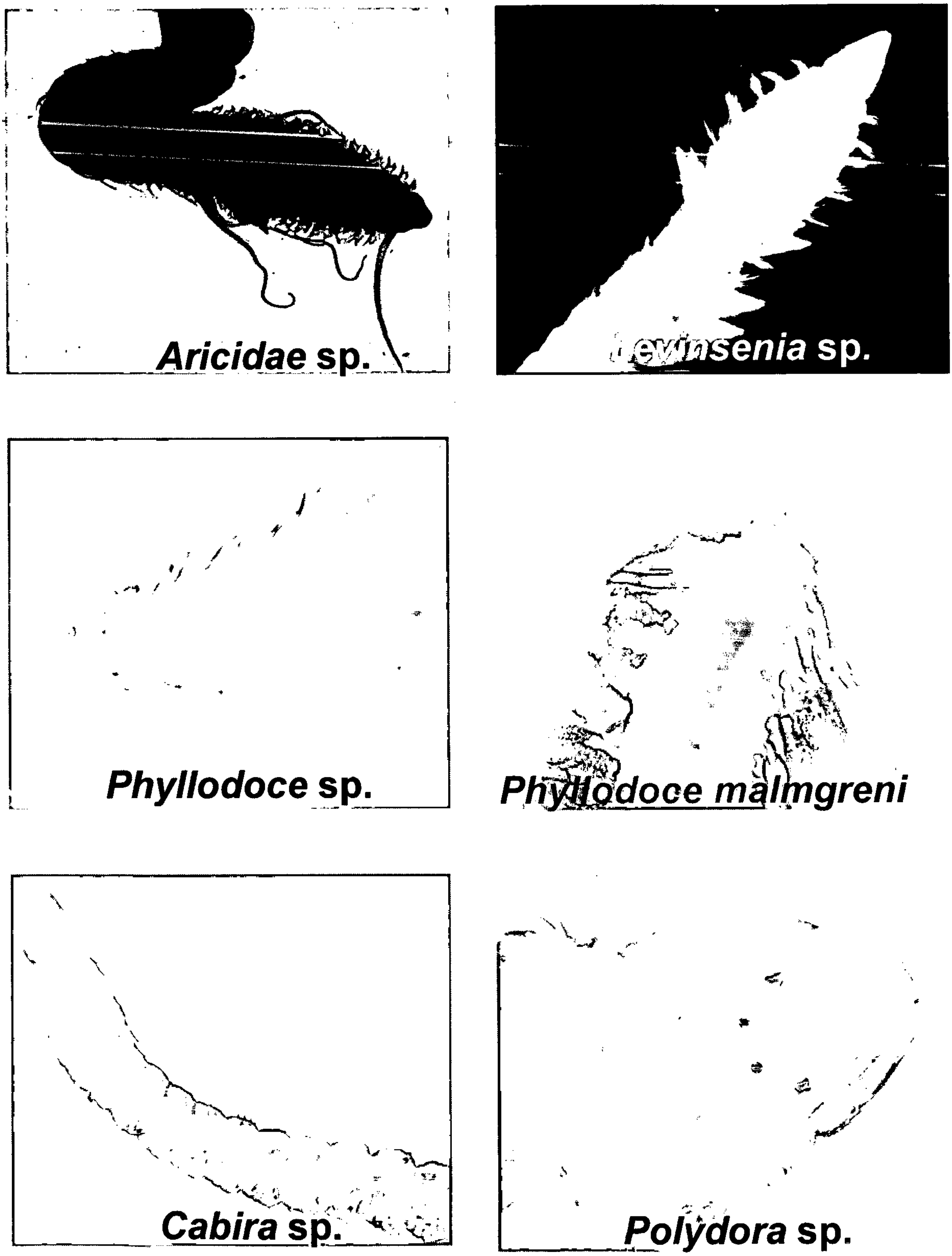
Sthenelais sp.



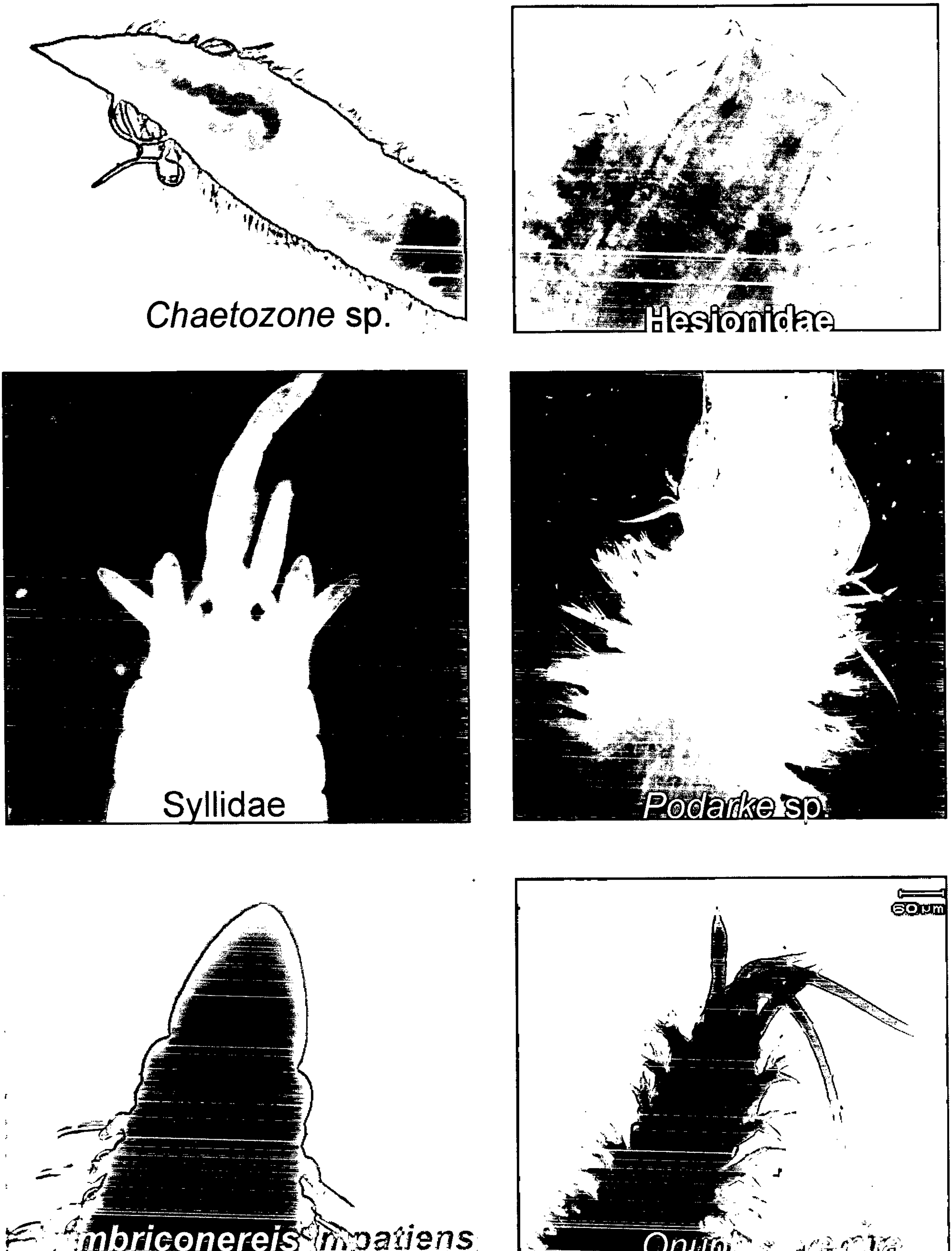
Lumbriconereis sp.

Staur

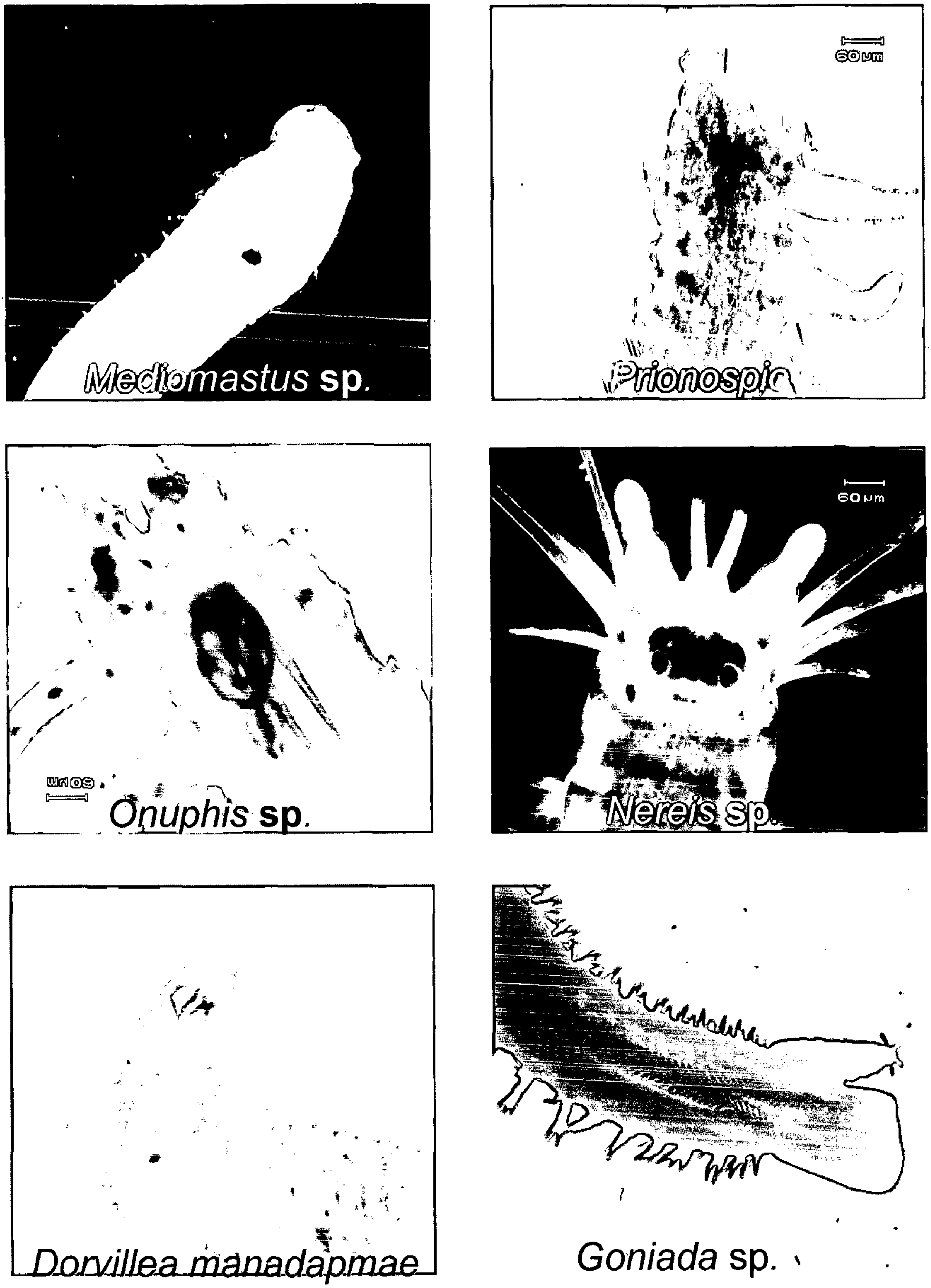
Polychaetes of west coast of India



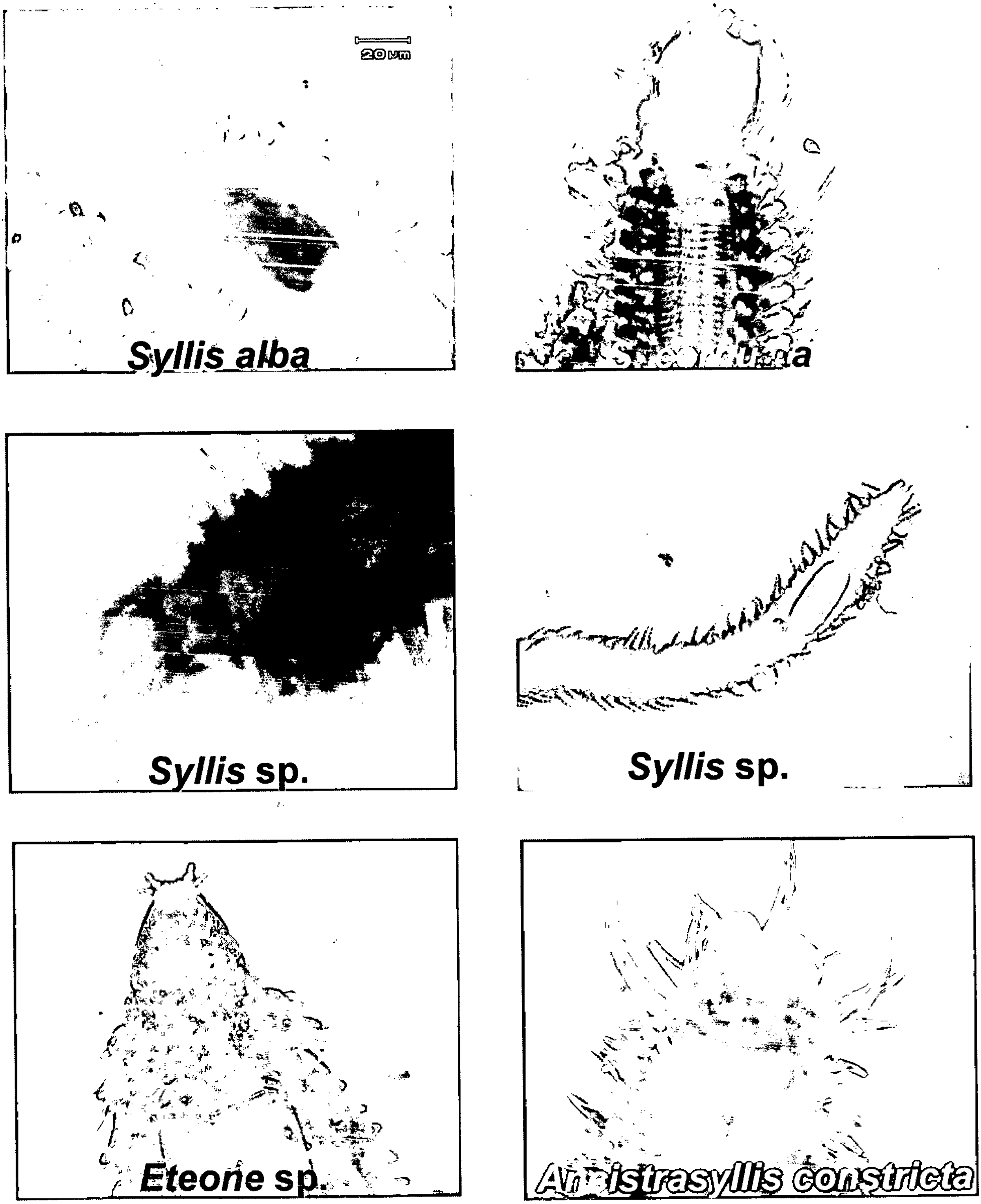
Polychaetes of west coast of India.



Polychaetes of west coast of India



Polychaetes of west coast of India



Polychaetesof west coast of India.

Summary and Conclusions

Summary and Conclusions

Marine ecosystems constitute the largest aquatic system on the planet, covering over 70% of the Earth's surface. The organisms that inhabit the marine sediments constitute the largest faunal assemblages on Earth. The macrofauna (>500μm size) forms the dominant biomass of organism in marine sediment. They play an important role in ecosystem processes such as secondary production, nutrient recycling and pollutant metabolism.

A fundamental concept in ecology is the interaction between the organism and their environment. Studying the variability in communities at spatio-temporal scales, the impact of anthropogenic on the macrobenthic community can be assessed. Studies considering the community level response to pollutants and experimental disturbance are limited from the west coast of India. The importance of experimental disturbance on the communities or populations allows understanding the factors affecting the distribution and recolonisation of species. Experimental disturbance study should be done on communities or population and not on a single species. Furthermore, including the natural variability of ecosystems in experimental studies helps to better understand responses of communities to changes and discriminate between natural and simulated disturbance. Therefore, ecology of macrobenthic community along with simulated disturbance experiment have been attempted to gain a better understanding of the response of macrofauna to pollution, which was the main aim of this thesis. The present study focused on three major threats to the west coast of India viz., harbour activities, oil spill and sand mining.

Mormugao Port is one of the oldest ports on the west coast of India. It has a fine natural harbour and one of the best deep water ports in the Indian sub continent. Sampling was carried out at seven locations in the harbour, for environmental parameters and macrobenthos. Macrofauna of the area showed seasonal variation in dominance of species. The polychaete *P.pinnata* and *Tharyx* sp. dominated during monsoon which was replaced by the bivalve *T.scabra* in post monsoon. *Cossura* sp. was the dominant species in pre monsoon. Although *T. scabra* dominated the faunal community during post monsoon, it showed drastic decline in pre monsoon. A similar decline was observed in the other macrofaunal species. Therefore, the macrofaunal community in the harbour area did not follow the seasonal variation generally observed in the tropical estuaries.

Increased harbour activities during pre monsoon allowed only those species that can tolerate the stress to survive. The present data was compared with earlier published data from the region. The data indicates that the macrofaunal species have changed through the years. While the community was dominated by polychaetes in the present and past study, the major change was observed in crustacean, the second dominant group. The crustaceans in this study were observed only during the post monsoon and with low abundance. Even among polychaetes which dominate the macrobenthic community, the species composition showed shift from a carnivores dominated community to deposit feeding species. The shift may due to the change in the food availability in the area. The organic carbon showed an increase from previous reports. Increase in food may have facilitated the increase in the deposit feeding species. However, when compared to many of the other harbours around the world, the area did not show defaunation. This could be because of the strong hydrodynamic conditions in the Mormugao harbour, which flushes the contaminants out of the system and keeps the area well oxygenated. The heavy monsoonal runoff further helps in flushing the Zuari estuary.

Dredging is one of the major disturbances in the harbour and routinely carried out to maintain the navigable depth. One time dredging is carried out during the construction of new structures or extension of the existing one. The present study looked into the impact of one times dredging on the macrobenthic community of the Mormugao harbour and the time required by the community to recolonize. The sediment texture did not show significant variation at the dredged site after dredging. However, there was increase in suspended solids in the dredged station. The community in the dredged station was dominated by *C.scabra* which showed >90% decline as dredging progressed. However, decline in the macrofaunal abundance was observed in the adjacent and control station. However, it was difficult to asses the impact of dredging as the dredging was followed by monsoon season. The rough monsoon is known to cause the defaunation of the estuarine fauna, which is followed by recruitment in post monsoon. It can be concluded that one time dredging will have minimum impact on the macrobenthic community in areas with strong hydrodynamics. The impact of dredging on the macrofaunal community may occur only if dredging is carried out frequently as seen in the channel station. The channel station had lowest abundance and species richness through out the study period.

Studies comparing the macrobenthic community between different Indian harbours are limited. The present study was therefore conducted in three important harbour (Ratnagiri, Mormugao, Karwar) along the central west coast of India. This chapter discusses the health status of the three harbours diagnosed using various biotic indices. 55 macrobenthic taxa were identified. Biomass was high and was made largely by echiurans (>80%). Overall, polychaete dominated the macrobenthic diversity. Opportunistic *P.pinnata*, *Notomastus* sp. and *Mediomastus* sp., dominated the macrobenthic community responding to the increased in the harbour activities. Biotic indices (P:A ratio, ABC curve and geometric class abundance) and the dominance of opportunistic species indicate that, the three harbours are under stress from anthropogenic activities.

Oil pollution is a major environmental problem and is important, in particular, to the Indian coastline as two main ship routes pass through the Arabian Sea. Oil spills data indicates that accidental spills/accidents have shown an increase along the Indian coast. Aim of this chapter was to review the impact of frequent spills on benthic community and marine fishery, in general. Data was collected from various sources for the present work. Further, majority of the spills occurred during the SW monsoon period, which coincides with the recruitment period of most commercial and non-commercial species. Therefore, although the volume of spill is small, frequent occurrence and the occurrence during the crucial stage of the life cycle may have a long-term impact on the population of marine organisms.

India has some of the largest placer mineral resources in the world. Kalbadevi along the Ratnagiri coast in Maharashtra is reported to have rich deposit of illmenite - an ore of titanium. Although India has 35% of world reserve of illmenite, it contributes to mere 4% of the total production. Therefore, these areas with economical mineral deposits are potential site for future mining. The present work is part of an EIA study aimed to build up a baseline data of the macrofaunal community of the area. Seasonal sampling was carried out in the intertidal and subtidal region. Simulated mining experiment was also carried to study the immediate impact of mining on the coastal ecosystem and the time required for recolonisation in the disturbed site.

The intertidal and subtidal region of Kalbadevi showed a rich macrofaunal community. The macrofauna in the intertidal region was dominated by the gastropod, *U. vestiarium*. *Jasmineria* sp. *Mediomastus* sp. and *P. pinnnata* were the dominant species of the subtidal area. Unlike the Mormugao harbour, the community in Kalbadevi followed the conventional pattern in seasonal faunal variability. The one-time experimental disturbance carried in the intertidal and subtidal region showed minimal impact on the macrofaunal community. Further, the seasonal variability was superimposed on the simulated mining and hence it was difficult to demarcate the difference between natural and experimental disturbance.

It can be concluded that the west coast of India showed signs of stress from activities as evident from species composition, univariate and multivariate indices. However, the impact was restricted to the harbour area. This may be due to the location of the harbour towards the estuarine mouth. The hydrodynamic nature of the river helps to maintain the oxygen level. The heavy runoff during monsoon further flushes the entire estuarine system. Though the area is dominated by opportunistic species complete defaunation was not seen like many harbours.

The study also provides baseline data of the macrofaunal community from ilmenite rich area. The macrobenthic community was diverse and well represented by different groups. The simulated mining did not show detrimental changes in the macrobenthic community of the area as hypothesized before. The study also indicated that the community takes >1 year for recolonization. Commercial mining will not eliminate the macrofauna completely as long as the undisturbed area can maintain the population. However, the present data need to be interpreted with caution as the experiment did not reach the level of full scale mining experiment. Mining activities should be designed to minimize impact on biological resources and to ensure the biological assemblages that recolonize are similar to that present prior to mining. Facilitating rapid recolonization of a mined area would minimize alteration of community structure and function and reduce potential effect upon trophically dependent higher organism.

The importance of studying the spatial-temporal patterns of macrobenthic community is required as they form the basis for further work. The present study will contribute to our understanding the variability and management of the coastal ecosystem of India. Many of the species identified are well documented. However very little is known about their biology, reproduction and interaction with other species. Further, many of the organisms were not identified up to species level due to lack of literature. It is required to build a database of the macrofauna species for future management of this ecologically and economically important coast of the country. Developing such database will be a key to understand the ecosystem interactions and the processes that control regional and local biodiversity.

Treat the earth well

as we do not inherit the Earth from our ancestors,

we borrow it from our children.

Ancient Kenyan Proverb

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Publications

Research Publications

- Sivadas **Sivadas S**, Gregory A, Ingole B (2008). How vulnerable is Indian coast to oil spills? Impact of MV Ocean Seraya oil spill. *Current Science*. 95 (4): 504-512.
- Ingole BS, **Sivadas** S, Nanajkar M, Sautya S, Nag A (2008) A comparative study of macrobenthic community from harbours along the central west coast of India. *Environmental Monitoring and Assessment* **(Online).**
- Ingole BS, **Sivadas S** (2007) The Slippery Coastline, *Voice Greenglobe.* A Greenwoods Media Pub, October 32-37 pp.
- Ansari ZA, **Sivadas S,** Ingole BS (2007) Benthic macrofauna, in: The Madovi and Zuary estuaries (ed. By S.R. Shetye, M. Dileep Kumar & D. Shankar), pub. NIO Goa.
- Ingole BS, **Sivadas S**, Goltekar R, Clemente S, Nanajkar M, Sawant R, D'Silva C, Sarkar A, Ansari ZA (2006) Ecotoxicological effect of grounded *MV River Princess* on the intertidal benthic organism off Goa. *Environment International*. 32:284-291.
- **Sivadas S**, Sautye S, Nanajkar M, Ingole BS (2005) Potential impact of sand mining on macrobenthic community at Kalbadevi Beach, Ratnagiri, West coast of India. Proc. Nat Sem. Development Planning of Coastal Placer Minerals (PLACER - 2005). (eds) Loveson, V.J.; Chandrasekar, N.; Sinha, A., Allied Pub. New Delhi, 264-270pp.

interference, we use only the second row of S and keep all other samples of D together. To preserve the signal content, an edge effect-free prediction filter is designed, which is able to preserve the primary signal as the filter never exceeds the edge of the 3D data slice.

The most common SI originates from other seismic sources working in the same area at the same time. This has been studied by the application of f–x–y prediction filters in the f–x domain and tested on a new dataset from the Gulf of Mexico with a long streamer configuration of 9000 m. The input RMS noise plot from a line that was contaminated with seismic interference is plotted for the first 350 traces (for better resolution) as shown in Figure 3 *a*. The amplitude of the SI varies from 15 to 30 μbar. The output of the process is given in Figure 3 *b*. In the dataset, where signal and high-amplitude SI are present together, the process preserves the signal while attenuating SI.

Interference noise and random noise have also been studied on the stack sections which are also contaminated. An example of the seismic stack section from a different line in the Gulf of Mexico is presented in Figure 4 *a*. High-amplitude SI and random noise are clearly visible on the stack section. The f–x–y prediction filter technique identifies and removes SI from stacks belonging to a single subsurface line of a 3D marine recording. Hence it is applied to the original data (NMO corrected) to eliminate SI (Figure 4 *b*). The difference between the raw and denoised stack is calculated as shown in Figure 4 *c*. Another example from a different area is shown in Figure 5.

Depending on the type of survey, significant level of seismic interference can drastically reduce the true prospects of an area. Standard 3D processing can provide some attenuation of seismic interference but cannot eliminate it completely. The method described here combines inline and crossline f–x prediction filters in detecting and attenuating ST on 3D marine seismic data from the Gulf of Mexico. This approach maximizes signal fidelity while avoiding the transform artifacts found in other methods. In this method the direction as well as amplitude of seismic interference do not matter. Thus the asynchronous character of the interference is the only condition for the success of this technique. In this way, a frequency that does not contain interference noise can be treated differently from frequencies that do.

The present study suggests that application of inline and crossline f–x prediction filters efficiently eliminates noises generated by neighbouring ships as well as the random noise. We observe that the process preserves reflection energy while suppressing SI and enhances spatial continuity. This will reduce the financial risk associated with advanced seismic processing for fluid/lithology discrimination and the imaging of saturation and pressure changes using time-lapse seismic data.

Quality control during seismic data acquisition is governed by predefined specifications or 'specs'. A spec defines the extent to which a given component of the acquisition system is allowed to degrade before it must be repaired or acquisition must be delayed. All specs should be reconsidered periodically to ensure that they take into account advances in acquisition and processing technology, as well as new demands in interpretation. Only through adherence to properly chosen specs can one obtain data that, after processing, will yield results not unacceptably compromised by choices made in the acquisition.

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How vulnerable is Indian coast to oil spills? Impact of MV *Ocean Seraya* oil spill

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On 30 May 2006, a bulk carrier, MV *Ocean Seraya* ran aground along the Karwar coast spilling 650 tonnes of oil. Due to the rough SW monsoon, the spill spread to some beaches in south Goa. The aim of this communication is to study the immediate impact of oil spill on benthic ecology. We have also reviewed the impact of frequent spills on the benthic community in

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particular, and marine fishery in general. Intertidal sampling was carried out on 10 June 2006. Organic carbon (1%) and petroleum hydrocarbon (13 μg g^{-1}) were highest at Polem, as it was closest to the spill site. Twenty macrobenthic taxa which included crustaceans and bivalves were identified. Although the study is based on short-term sampling, it showed an increase in petroleum hydrocarbon in the sediment. A review of the oil spill data indicates that accidental spills have shown a decline globally, in contrast to increase in maritime transport. However, a reverse trend was observed along the Indian coast for the Arabian Sea. Further, majority of the spills occurred during the SW monsoon period, which coincided with the recruitment period of most commercial and non-commercial species. Therefore, although the spills occurring along the west coast are of small volume, frequent occurrence, particularly during the critical stages of the life cycle of organism, may have a long-term impact on the marine biota.

Keywords: Benthos, fishery, MV *Ocean Seraya* spill, organic carbon, petroleum hydrocarbon.

OIL pollution of the marine environment has been an issue of considerable national and international concern. India relies heavily on the marine environment for trade and commercial operations. Further, two major oil choke points of the world – Strait of Hormuz and Strait of Malacca lie on the west and east coasts of India. Due to the narrowness of these lanes, the routes are accident-prone. Moreover, import of oil and gas is growing faster than the demand, particularly in the developing countries led by China and India. The world's demand for petroleum products has been estimated[1] to go up from 84 mb/day in 2005 to 116 mb/day in 2030. The risk of major oil spill occurring along the west coast of India is considerably higher now, as there has been a significant increase in all types of maritime trade. A major oil spill could cause widespread ecological damage, and cripple or destroy marine commercial operations. Therefore, continued discharge of oil into the sea can pose a potential risk of severe pollution to the sensitive coastal ecosystem.

Goa, located along the mid west coast of India, also lies along the oil tanker route. Since 1994, four spills have been reported (Figure 1) along the small coastal strip of Goa. Grounding of MV *Ocean Seraya* on the Karwar coast was reported to have affected the beaches in south Goa from Polem to Benaulim. Earlier, in August 2005, large deposits of tarballs were reported from the beaches in south Goa (www.nio.org). In view of the increased incidents of oil spills, it was felt necessary to analyse and discuss the impact of oil spills on the benthic community and coastal fishery. Therefore, the present study was carried out to assess the immediate response and damage, if any, to the intertidal benthic community at Polem, Agonda and Benaulim. We also discuss the potential impact of frequent oil spills on the macrobenthic community and marine fishery.

MV *Ocean Seraya*, a Panamanian bearing flag bulk carrier carrying 650 tonnes of fuel oil and 40 tonnes of diesel, drifted and ran over submerged rocks off Karwar on 30 May 2006 (Figure 2). On 2 June 2006, the oil spill touched Polem beach on the Goa–Karnataka border. Due to the monsoon winds, the impact of the slick was also visible more than 20 km away in south Goa at Palolem and Canacona.

Polem (74°4′E, 14°54′N) and Agonda (73°59′E, 15°2′N) are situated in the southern most part of Goa (Figure 1). Benaulim (73°50′E and 15°15′N) forms a part of the long stretch of shallow, sandy beaches, interrupted by Zuari river in the north and Sal river in the south.

Field sampling was carried out on 10 June 2006 during low tide at Polem, Agonda and Benaulim. Samples for macrobenthos were collected using an acrylic core (Ø 12 cm). Sediment from the surface down to a depth of 10 cm was collected, sieved and preserved in neutralized 5% formaldehyde–Rose Bengal solution. Sediment was collected separately for organic carbon (OC) and petroleum hydrocarbon (PHC) using an acrylic core (Ø 4.5 cm). Temperature (sediment, air and water) and salinity were recorded using a field thermometer and refractometer respectively.

In the laboratory, macrofauna were sorted, identified, counted and biomass was estimated by the wet weight

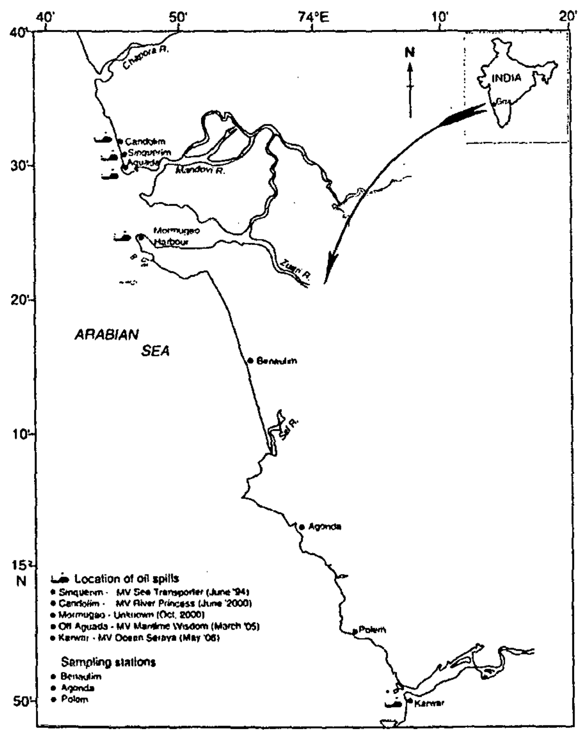

Figure 1. Map showing the location of the study area.

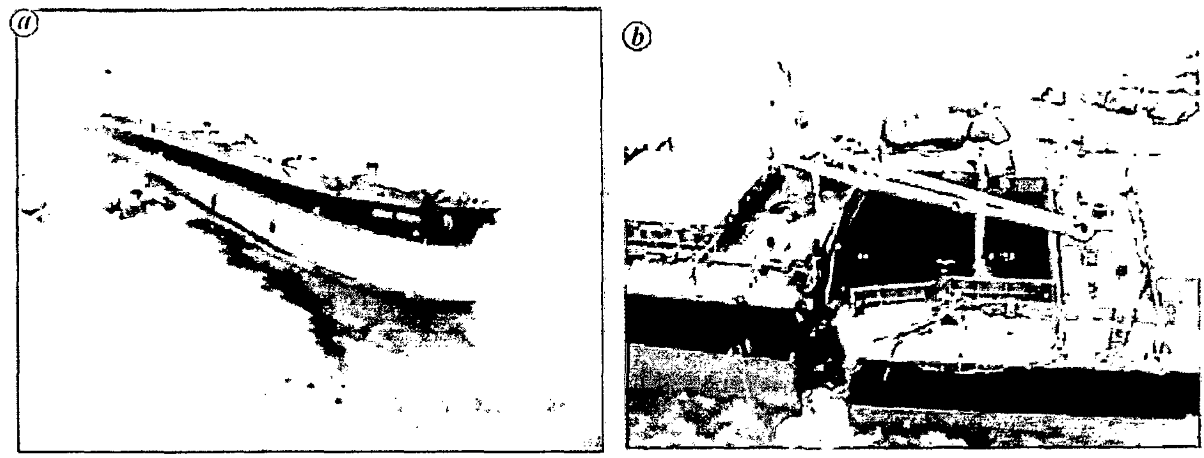

Figure 2. Grounded vessel MV *Ocean Seraya* off Karwar coast (source: Indian Coast Guard).

Table 1. Environmental parameters in the study area

	Temperature (°C)			Salinity (psu)	Surface water (μg l^{-1})	
	Sediment	Water	Air	Water	Chlorophyll	Phaeophytin
Polem	26	28	28	15	0.11	0.31
Agonda	27	29	26	29	0.42	1.28
Benaulim	–	–	–	30	0.57	1.93

–, not available.

method. Mole crab, *Emerita holthuisi* and the wedge clam, *Donax incarnatus* were dominant in terms of faunal abundance. Therefore, the populations of both species were counted as adult and juvenile. The females of *E. holthuisi* carrying eggs were again separated for further analysis. All the eggs were separated, enumerated and studied for any abnormalities. Sediment OC was estimated using the wet oxidation method[2] and PHC by hexane extraction[3]. Chlorophyll and phaeophytin were estimated by acetone extraction method[4].

The structure of the benthic community at each site was calculated in terms of number of species (*S*), total abundance, total biomass, Shannon–Weiner species diversity index (*H'*), evenness (*J*) and species richness (SR) using PRIMER[5]. The faunal density data were subjected to multidimensional scaling (MDS) ordination and Bray–Curtis cluster analysis. Correlation was sought between the biological factors (macrofaunal abundance, biomass and diversity) and sedimentary (OC, chlorophyll *a* (chl *a*) and PHC) parameters.

MV *Ocean Seraya* ran aground off the Oyster Rocks in Karwar, spilling 650 tonnes of fuel oil. The spill started spreading towards the Goa coast due to the rough SW monsoon winds. Frequent occurrence of tarballs and oil pollution along the beaches of Goa is a major threat to the tourism, which is one of the main employment-generating industries in the state. About two million tourists (both domestic and foreign) visit the Goan beaches every year, which accounts for 12% of all the tourist arrivals in India. There are around 439 medium and 11 five-star hotels in Goa. Oil spills not only affect ambience of the beaches, but are also known to affect the coastal ecology and fishery on a long-term basis[6].

Environmental parameters (temperature: air, sediment, surface water; salinity) observed were in accordance with those recorded normally during the monsoon season (Table 1). Salinity ranged between 15 and 30 psu. Low salinity recorded (15 psu) at Polem was mainly due to heavy rains on the sampling day. The values for surface water chlorophyll were highest (0.57 μg l^{-1}) at Benaulim.

Sediment chl *a* ranged from 0.01 to 0.03 μg g^{-1}, with the highest value at Benaulim. OC values ranged from 0.2 to 1%, Polem showing the higher value (Figure 3 *a*). PHC level in the sediment varied from 1.97 to 13 μg g^{-1} (Figure 3 *b*). Higher PHC was recorded at Polem and the lower at Agonda. The higher PHC observed at Polem was due to its close proximity to the oil spill site. Lower values of PHC at other stations could have been due to its dilution, which increases with distance from the spill site. The average sediment hydrocarbon level along the Goa coast was observed[7] to be 7.1 μg g^{-1}, indicating that PHC was higher at Polem compared to the other beaches. Experimental evidence suggests that about 56% of the spilled oil is adsorbed onto the bottom sediment[8], where oxidation may take place over several years[9]. Oil stranded from *Exxon Valdez* persisted for >10 years on some boulder-

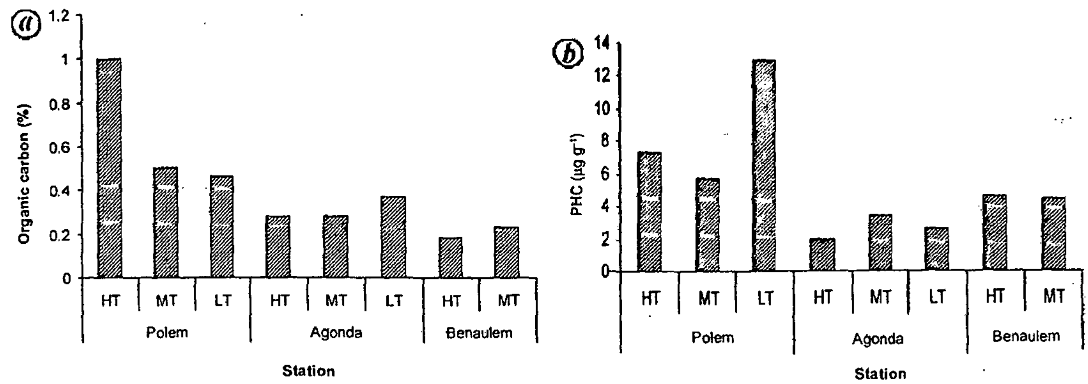

Figure 3. Organic carbon (*a*) and petroleum hydrocarbon (PHC) (*b*) concentration in the study area (June 2006).

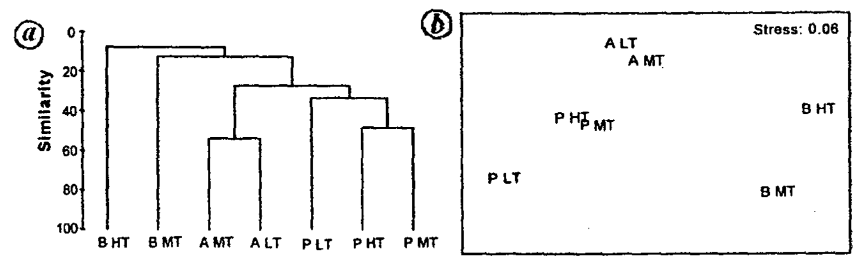

Figure 4. Cluster (*a*) and MDS (*b*) based on macrofaunal abundance. B, Benaulim; A, Agonda; P, Polem; HT, High tide; MT, Mid tide; LT, Low tide.

armoured beaches bordering the Gulf of Alaska. These sites are 300–700 km away from the spill and the oil was chemically similar to the 11-day oil of *Exxon Valdez*[10]. Thus, the degree of oil pollution in the marine environment may be more accurately assessed by measuring oil in the sediment[11] and the impact of oil spill can be well evaluated through benthic fauna[6].

A total of 20 macrobenthic taxa were identified from the intertidal area during the present study. The macroinvertebrates at Polem were dominated by Nemertean, followed by Polychaeta. *Macropthalamus* sp. (45%) and *Pisione oerstedii* (37.5%) were the most dominant polychaetes. In Agonda, crustaceans dominated the intertidal community. *E. holthuisi* was the most abundant in terms of population counts and biomass. Juveniles of *E. holthuisi* dominated the population and contributed to >80% of the total abundance. The mature *E. holthuisi* measured 13–18 mm and fecundity ranged from 500 to 2880. Most of the eggs were in early development (stages I and II)[12] and did not show any abnormality. The major spawning of *E. holthuisi* extends from December to June, with a peak in March and supplementary minor peak in October[13]. As a result, individuals are being recruited almost throughout the year. However, the main recruitment period along the Goan beaches appears to be during June–July[13]. Corroborating with earlier findings[14], abundance of *D. incarnatus* and *Gastrosaccus* sp. was higher at Benaulim beach. Clustering and MDS plot showed that all the three study areas differ in macrofaunal community (Figure 4). In Benaulim, mid tide was dominated by *D. incarnatus* (2872 ind m^{-2}) and high tide was represented by a low abundance of the polychaete, *Saccocirrus* sp. (22 ind m^{-2}) and the isopod, *Eurydice* sp. (22 ind m^{-2}). In Polem, Nemertean dominated in the high tide (265 ind m^{-2}) and mid tide (155 ind m^{-2}) whereas low tide was dominated by polychaetes (884 ind m^{-2}). Similarly, Agonda (mid tide and low tide) clustered at 54% due to the presence of the bivalves, *D. spiculum* in similar density (552 ind m^{-2}).

PHC content in the sediment was negatively correlated with macrofaunal density. Though the present study did not show direct impact of oil spill from MV *Ocean Seraya* on the intertidal macrobenthic community, PHC values were high (13 µg g^{-1}) at the site closest to the spill (Polem). Sediment-associated oil from major spills has been shown to persist in the marine environment for years, and can be re-released in potentially toxic concentrations[15]. Dauvin[16] suggested that intertidal benthic communities are generally sensitive to oil spills, but the effects of oil pollution strongly depend on the proportion of hydrocarbon-sensitive species, especially crustaceans. While discussing the short- and long-term impact of oil

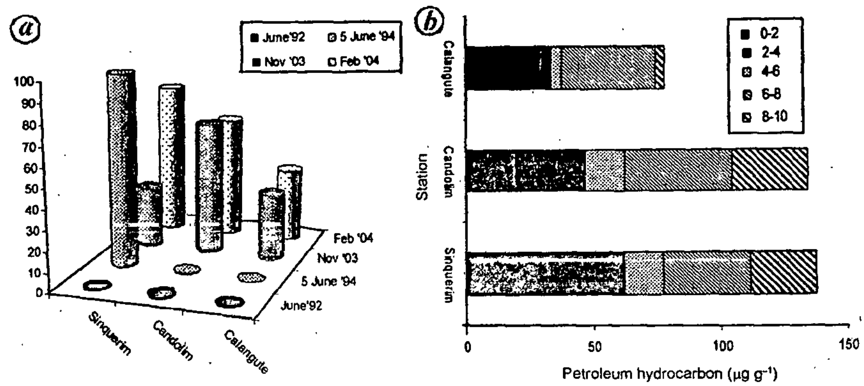

Figure 5. Variation in PHC concentration (*a*) and vertical distribution of PHC (*b*) at Sinquerim–Calangute–Candolim.

Table 2. Macrofaunal abundance in the study area

	Abundance (ind m^{-2})	Biomass (g m^{-2})	No. of species	Dominant group
Polem	1635	0.99	9	Polychaeta
Agonda	7499	9.6	11	Nemertenia
Benaulim	6419	448	7	Bivalvia

spill from grounded MV *Sea Transporter* on the intertidal meiobenthic communities, Ansari and Ingole[17] indicated that the short-term effect of oil spill was severe as most of the microscopic organisms were eliminated from the intertidal habitat. Strong wave action on the open beach and manual beach cleaning by the local administration assisted in reducing PHC content in the sediment. This resulted in faster recovery of meiobenthic communities. On the other hand, while studying the impact of oil spill from another grounded vessel, MV *River Princess*, Ingole *et al.*[6] demonstrated that relatively small-scale but persistent oil spill not only reduced benthic standing stock (abundance and biomass), but also some of the oil-sensitive species were eliminated. PHC concentration was high at the grounded site (Candolim) and the concentration in the area showed further increase from 43 to 58 μg g^{-1} (Figure 5 *a*). Increased PHCs in sediment was due to possible leakage from the grounded MV *River Princess* vessel[6]. Further, hydrocarbon values were highest in the sediment depth of 6–8 cm (Figure 5 *b*). The macrobenthic community of Candolim showed a decrease from 27 (ref. 18) to 11 (ref. 6).

The vulnerability of organisms to oil is related to seasonal changes in their distribution and abundance. Accordingly, for a particular species, spilled oil may have less impact during one part of the year than the another. Monsoon is the recruitment period for most of tropical benthic organisms and commercial fish. As is evident from the present study, major recruitment of *E. holthuisi* occurs during monsoon, as the *Emerita* population was dominated by juveniles (>80%). More than 90% of the benthic organisms have planktonic larvae[19]. Generally, the effect of oil spills is first observed in the pelagic organism. An oil spill is not stationary in the water column. It spreads over a larger surface area under the influence of winds (monsoonal or otherwise), during which it affects the pelagic organisms.

In contrast to the increase in oil consumption, resulting in increase in maritime transportation, incidents of accidental oil spill have shown a decrease globally since the 1970s. Tanker spills annually account for 12% of the oil entering the sea and a total of 531 spills have been reported[20] internationally from 1979 to 2004. Among the accidental tanker spills, 34.4% occurred due to grounding of vessel and 28.3% due to collisions[20]. According to Clarke[21], most of the oil affecting the marine ecosystem is derived from tanker operations and accidents. However, compared to the decrease in oil spills incidents globally, the number of tanker spills/accidents has increased along the Indian coast. Of the total observed spills, 70% were reported from the west coast of India (Table 3; Figure 6 and 7). Moreover, the data also revealed that majority of the spills occurred during the SW monsoon period. Model studies, based on historical data of winds and surface currents indicate that during the SW monsoon, the along shore surface currents developed an easterly shoreward component[22,23] resulting in rough weather conditions. This makes the west coast vulnerable to any oil spills in the Arabian Sea during the SW monsoon. The spawning periodicity of majority of marine organisms and commercial fishes coincides with the monsoon season so that their larvae could utilize the abundant plank-

Table 3. Major oil spills on the Indian coast since 1970

Date	Quantity spilled (t)	Position	Vessel/other incidents
Aug '70	15,622/FO	NW coast of India (off Kutch)	Greek oil tanker *Ampuria*
Jun '73	18,000/LDO	NW coast of India of the Arabian Sea	MT *Cosmos Pioneer*
Sep '74	3325/FO	Kiltan, Lakshadweep	American oil tanker *Transhuron*
Jul '76	29,000	Off Mumbai	*Crestan Star*
Jun '79	11,000	Cochin	*Aviles*
1982	NK	West coast	*Sagar Vikas*
Oct '88	1000	Bombay Harbour, Maharashtra	*Lajpat Rai*
1989	NK	West coast	*SEDCO 252*
Jun '89	5500	795 n mile SW of Mumbai	MT *Puppy*
Aug '89	NK	Bombay Harbour	ONGC tanker
Aug '89	NK	Saurashtra coast, Gujarat	Merchant ship
Aug '89	NK	Bombay Harbour	NK
Mar '90	NK	NW of Kochi, Kerala	Merchant ship
Sep '91	692/FO	Gulf of Mannar, Tamil Nadu	MT *Jayabola*
Nov '91	40,000/crude	Bombay High, Maharashtra	MT *Zakir Hussain*
Feb '92	Tanker wash	40 n mile south of New Moore Island, Bay of Bengal	Unknown
Apr '92	1000/crude	54 n mile west of Kochi, Kerala	MT *Homi Bhabha*
Aug '92	1060/SKO	Madras Harbour, Tamil Nadu	MT *Albert Ekka*
Nov '92	300/FO	Bombay Harbour, Maharashtra	MV *Moon River*
Jan '93	40000	Off Nicobar	Maersk navigator
Mar '93	NK/crude	Off Narsapur, Andhra Pradesh	ONGC rig, Kumarada
Apr '93	110/crude	Bombay Harbour, Maharashtra	MT *Nand Shivchand*
May '93	90/FO	Bhavnagar, Gujarat	MV *Celelia*
May '93	6000/crude	Bombay High, Maharashtra	Riser pipe rupture
Aug '93	260/FO	Off New/Mangalore	MV *Challenge*
Oct '93	90/crude	Cochin Harbour, Kerala	MT *Nand Shivchand*
May '94	1600/crude	Off Sac Romanto	*Innovative-1*
May '94	-/FO	360 NM SW of Porbandar	MV *Stolidi*
Jun '94	1025/crude	Off Aguada Lighthouse, Goa	MV *Sea Transporter*
Jul '94	100/FO	Bombay Harbour, Maharashtra	MV *Maharshi Dayananad*
Nov '94	288/HO	Off Madras, Tamil Nadu	MV *Sagar*
Mar '95	200/diesel	Off Vizag, Andhra Pradesh	Dredger *Mandovi-2*
Sep '95	-/FO	Off Dwarka, Gujarat	MC *Pearl*
Nov '95	Tanker wash	Eliot beach, Chennai	Unknown
May '96	370 FO	Off Hooghly River	MV *Prem Tista*
Jun '96	120/FO	Off Prongs Lighthouse. Maharashtra	MV *Tupi Buzios*
Jun '96	132/FO	Off Bandra, Maharashtra	MV *Zhen Don*
Jun '96	128/FO	Off Karanja, Maharashtra	MV *Indian Prosperity*
Jun '96	110/FO	Off Worli, Maharashtra	MV *Romanska*
Aug '96	124/FO	Malabar coast, Kerala	MV *Al-Hadi*
Jan '97	Tank wash	Kakinada coast, Andhra Pradesh	Unknown
Jun '97	210/FO	Off Prongs Lighthouse, Maharashtra	MV *Arcadia Pride*
Jun '97	NK	Hooghly River, West Bengal	MV *Green Opal*
Sep '97	Naptha, diesel petrol	Vizag, Andhra Pradesh	HPC refinery
Aug '97	70/FO	Off Mumbai, Maharashtra	MV *Sea Empress*
Jun '98	20/crude	Off Vadinar, Gujarat	Vadinar, SBM
Jun '98		Off Porbandar, Gujarat	Ocean barge
Jun '98		Off Veraval, Gujarat	Ocean Pacific
Jul '98	15/FO	Mul Dwarka, Gujarat	*Pacific Acadian*
Jul '00	–	Off Sagar Island, West Bengal	MV *Prime Value*
Sep '00	–	Off Fort Aguada, Goa	MV *River Princess*
Dec '00	1/FO	Bombay Harbour, Maharashtra	MV *Stonewall Jackson*
Jun '01	–	Vadinar, Gulf of Kachchh	Not known
Jul '01		Hooghly River, West Bengal	MV *Lucnam*
Aug '01		SBM Vadinar, Gujarat	
Sep '02		220 n mile off Pt Calimare	MV *Hiderbahy*
Apr '03	1.8/light crude oil	5 miles off Kochi, Kerala	MT *BR Ambedkar*
May '03	145 FO	Off Haldia, West Bengal	MV *Segitega Biru*
Aug '03	300/crude oil	ONGC rig (BHN), Maharashtra	URAN pipeline
Feb '04	01/crude oil	ONGC pipeline at MPT oil jetty	Crude oil transfer
Oct '04	0.56	Berthed-MPT–8, Goa	
Mar '05	110	Off Aguada Lighthouse, Goa	MV *Maritime Wisdom*

(*Contd*)

Table 3. (*Contd*)

Date	Quantity spilled (t)	Position	Vessel/other incidents
Jun '05	49,537/cargo and 640/FO	Vishakhapatnam Port	MV *Jinan VRWD-5*
Jul '05	350 m^3 base lube oil	Mumbai Harbour	Dumb barge *Rajgiri*
Jul '05	33/FO	NE of Paget Island (N. Andaman)	MV *Edna Maria*
Jul '05	80	Off Prongs Lighthouse, Off Mumbai	OSV *Samudra Suraksha*
Aug '05	–	9 n mile off Tuticorin	MV *IIDA*
Sep '05	100	Off Visakhapatnam	MV *Royal Ocean 2*
May '06	650/FO	Oyster rocks, Karwar	MV *Ocean Seraya*
Aug '06	4500	Grear Nicobar Island	*Bright Artemis*

FO, Fuel oil; HO, Heavy oil; NK, Not known.

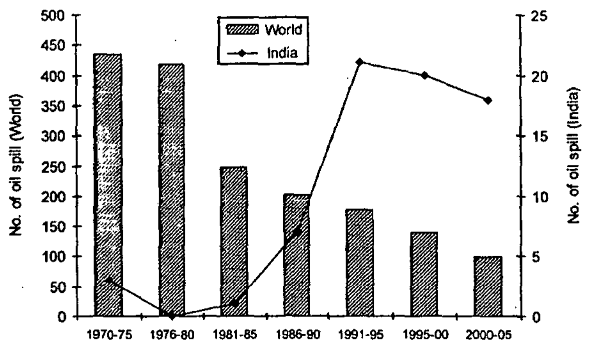

Figure 6. Comparison of oil spill incidents in the world and Indian waters.

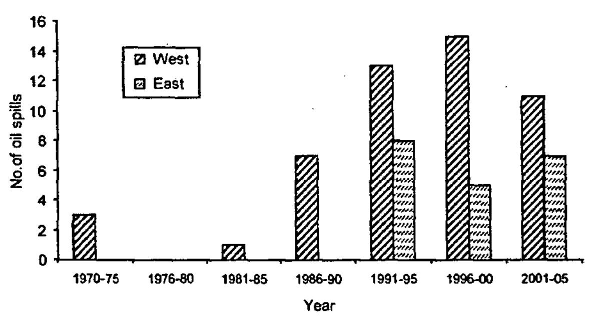

Figure 7. Comparison of oil spill incidents along the west and east coasts of India.

tonic food resulting from the seasonal upwelling[24]. Therefore, oil spills occurring during the critical stage of the marine organisms may have a long-term impact on the recruitment and population of the organisms.

Increasing data are available regarding the susceptibility of early developmental stages to oil, especially at the cellular and sub-cellular level, sometimes at substantially lower concentrations[25]. The cumulative impact of *North Cape* oil on winter flounder embryos was a reduction of 51% in the number of embryos surviving to the larval stage[26]. Naphthalene and phenanthrene, both light-weight PAHs, are among the most toxic fractions of oil[27]. When raw oil is exposed to sunlight, more persistent and toxic compounds are produced[28] and the peroxides induce mutation. Many of the commercial fishes exploit the near-shore area for spawning and development of sensitive embryonic and larval stages. This could work against these species when the area becomes contaminated with toxic material such as oil. Survival through planktonic development stages is believed to be the most important event controlling the abundance of marine organisms. Also the early stages of these species are vulnerable to significant losses due to natural events and will be further affected by anthropogenic disturbances like oil spills[26].

Benthos are the major food source for demersal fisheries and benthic production shows strong seasonality. Consequently, any impact on benthos will affect the demersal fishery production of the area. Analysis of benthic biomass distribution and demersal fish showed a positive correlation and high biomass area was found supporting greater density of bottom fishes[29].

The marine fish landing for the year 2004 was 635,094 tonnes along the west coast contributing to about 73% of the total marine fish catch of the country[30]. Fish catches have increased considerably in the last few decades. However, this has been attributed to mechanization and increase in the number of fishing trawlers as well as advancement in gear technology[31]. Landings of major fishery resources in the Indian Ocean region have declined significantly. Over-exploitation is attributed to be the main cause of decline in fish catches worldwide, which may be further affected by increase in oil spill occurrence.

Significant changes in commercial fish stocks take place in the inshore areas, although attempts are not usually made to link them with any single pollutant[32]. However, oil spills could be one of the reasons for fluctuation in total fish catch, as hydrocarbons can greatly reduce the individual organism's chances of survival[33] and accordingly, population changes are of potential concern. According to McIntyre[32], fisheries on the continental shelves are at a greater risk than those offshore, and this affects the shallow coastal intertidal areas.

Apart from accidental spills, oil pollution occurs during routine operations such as loading, discharging and bunkering, which are normally carried out in ports or at oil terminals. Concerns have arisen recently about the number of illegal discharges from the large volume of shipping within the region. After evaporation of the lighter fractions of oil and photooxidation, the heavier fraction gradually forms into tarballs. Driven by wind and current, these tarballs are deposited on the beaches. Periodic tar ball and raw oil pollution is observed at all the major beaches, mainly during the onset of monsoon and sometimes throughout the year. The life of tarballs in the sea varies from 33 to 58 days, while the same is not yet known for the beaches. However, due to the half yearly changes in surface circulation, these tarballs are deposited along the beaches of India, including Goa. Estimates from data for two years give 40 tonnes as the yearly deposit of tarballs along the beaches of Goa[34]. In August 2005, oil spill from an unknown source caused the deposition of tar along the major tourist beaches and heavy mortality of beach organisms[35]. Threats of oil contamination in the sea and the coastal area as a result of petrol-related activities and usage of petroleum and petroleum products are serious, since they could cause irreparable damage to the marine ecosystem, thereby affecting the socio-economic status of the population which depends on the coastal resources for its livelihood.

Further, residual oil from the oil spill carpets the seabed and remains in contact with the seabed for longer time, thus having a long-term effect on the benthic environment. The increasing trend of oil spills around the coast could certainly have a negative impact on the marine community, as observed earlier, as well as the economy in terms of fisheries and tourism. A comprehensive long-term investigation is therefore required to study the impact of oil pollution on coastal ecology that will help in conserving the coastal biodiversity.

The present study did not show any major impact of MV *Ocean Seraya* on the intertidal macrobenthic community of beaches in south Goa. However, PHC content was high at the site closer to the spill. India has had only relatively minor oil spills its coastal waters, primarily from tanker accidents. The possibility however of a major oil spill occurring along the Indian coast is considerably higher today, as there has been a significant increase in all types of oil tankers/bulk carriers/container ships passing through the Indian Ocean. Further, India also depends on sea transport for majority of its trade. Coastal areas all over the world have been reported to be damaged from pollution, thus having a significant effect on the marine ecosystem, on particular fisheries. Therefore, control of aquatic pollution has been identified as an immediate need for sustainable management and conservation of the existing fisheries and aquatic resources.

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Salmonella Typhimurium invasion induces apoptosis in chicken embryo fibroblast

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***Salmonella* Typhimurium induces apoptosis in macrophages and intestinal epithelial cells. In the present study we report that it induces apoptosis in chicken embryo fibroblast (CEF), by a scatter experiment using flow cytometry. This finding makes CEF the best model for molecular analysis of apoptosis induced by *Salmonella*, since culture and handling of CEF is more convenient than any other specialized cells.**

Keywords: Apoptosis, chicken embryo fibroblast, *Salmonella* Typhimurium.

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APOPTOSIS is a genetically determined form of cell death that plays a central role during development and homeostasis of multicellular organisms[1,2]. Necrotic cell death is usually the consequence of physical injury and does not involve active participation of the cell. Apoptosis can be distinguished from necrosis on the basis of several morphological as well as biochemical parameters, such as nuclear condensation, loss of cell volume, cell shrinkage, DNA fragmentation[2], and phosphatidylserine exposure to the outer face of the plasma membrane[3]. This kind of cell death avoids spillage of intracellular contents in contrast to necrotic cell death, typified by cell and organelle swelling and membrane disruption, resulting in an inflammatory response[3]. The central executioners of apoptosis are a set of cysteine proteases that are part of a large protein family known as caspases[4]. Apoptosis is critically important to development, tissue homeostasis, and in the pathogenesis of various viral and bacterial diseases[5].

The ability of *Salmonella* to promote apoptosis may be important for the initiation of infection, bacterial survival and escape of the host immune response[5].

Flow cytometry is a simple and reproducible method useful for assessing apoptosis of specific cell populations. There are several methods that can be used to quantitate apoptosis by flow cytometry. The simplest method based on biochemical changes includes use of propidium iodide (PI) to stain the DNA and look for the sub-diploid, or Ao population of cells from a cell cycle profile. Staining of isolated nuclei with DNA-binding fluorescent dye PI showed that intensity of fluorescence is correlated with the extent of DNA degradation[6]. Flow cytometric analysis of the apoptotic cell population can be carried out using either single dye or a mixture of dyes.

Salmonella induces apoptosis in macrophages and dendrocytes through the caspase-1 pathway. In the present study we have made an attempt to find whether *Salmonella* induces apoptosis in chicken embryo fibroblast (CEF). The isolates selected for the study were ML-4, ML-7 and ML-5.

Primary CEF culture was prepared. After 45 min of bacterial infection to the fibroblast, the infected cells were washed three times with PBS (7.4) and incubated in fresh tissue culture medium containing 100 μg of gentamicin/ml for 30 min. Then the cells were washed with PBS twice, followed by trypsinization.

For trypsinization, trypsin (0.1 ml/cm^2 of 0.25% trypsin in PBS) was added to the side of the flask opposite the cells. Then the flask was turned over and left stationary for 15–30 s and all but a few drops of the trypsin was withdrawn, making sure that the monolayer was not detached. The cells were further incubated for 5–15 min with flask lying flat, until the cells rounded up when the bottle was tilted and the monolayer was able to slide down the surface. At this stage of trypsinization, culture medium (0.1–0.2 ml/cm^2) was added and the cells were dispensed by repeated pipetting over the surface bearing

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A comparative study of macrobenthic community from harbours along the central west coast of India

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Abstract Harbours are heavily stressed coastal habitats characterised by high concentration of contaminant and low diversity of benthic community. The west coast of India harbours most of the major harbours compared to the east coast. Very few studies have compared the macrobenthic community between different Indian harbours. The present study was therefore conducted in three important harbour (Ratnagiri, Goa, Karwar) along the central west coast of India. The paper discusses the health status of the three harbours diagnosed using various biotic indices. Sediment samples were collected using van Veen grab (0.11 m^2) on board CRV Sagar Sukti. A total of 55 macrobenthic taxa were identified and were numerically dominated by polychaete. Biomass was high (0.14–145.7 g m^{-2}) and was made largely by echiurans (>80%). Overall, polychaete dominated the macrobenthic diversity. Opportunistic *P.pinnata, Notomastus* sp. and *Mediomastus* sp., dominated the macrobenthic community responding to the increased in the harbour. Biotic indices (Polychaete:Amphipod ratio, ABC curve and geometric class abundance) and the dominance of opportunistic species indicate that, the three harbours are under stress from anthropogenic activities.

Keywords Macrobenthos · Polychaetes · Harbour pollution · West coast · India

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Introduction

Harbours are the lifeline of a country's economy as bulk of the trade takes place through them. However, from the environmental point of view they are the most altered coastal habitats and cause considerable pollution of water, air and land. Further, several other activities like fisheries, industries and tourism occurs in and around the area that may have an impact on the environment. The harbours are characterised by reduced dissolved oxygen level and higher concentration of pollutants in water and sediment (Danulat et al. 2002; Rivero et al. 2005).

In general, levels of pollution along the Indian coast are increasing and the west coast perhaps, is more polluted compared to the east coast (Sengupta et al. 1989; Zingde 2002). This may be because most of the major harbours and ports are located along the west coast resulting in higher movement of transport vessels. In fact, two of the major oil routes of the world pass through the

Indian water and 70% of the world's oil is transported through this route (Anon 2003). In addition, over 53,684 mechanised trawlers and about 225,862 traditional fishing vehicles operate along the coastal waters of India (Somvanshi et al. 2003). Further, the west coast of India is recognized as biodiversity hotspot and contributes to >70% of the countries marine capture fishery.

Assessment of coastal ecosystem change can be effectively monitored using benthic fauna, as pollutant from any source will ultimately end in the seabed. The benthic communities play an important role in the transfer of materials from primary production through the detrital pool into higher trophic levels, including commercially exploitable fish (Bryan and Langston 1992; Ingole et al. 2006). The relation between the benthic standing stock and demersal fish resources has been very well documented for Indian waters (Harkantra 2004). Further, majority of the benthic fauna are sedentary and sessile and thus, cannot avoid any environmental perturbation (Danulat et al. 2002), hence are considered sensitive indicator of changes in the environment caused by natural and anthropogenic disturbances.

Mormugao is a major commercial port whereas; Karwar and Ratnagiri are minor ports along the central west coast of India. However, in recent years the commercial activities are on an increase in all the three harbours. In view of this, the respective state governments have considered the expansion. Further, the coastal waters between Ratnagiri and Karwar are recognized as active fishing zone (Madhupratap et al. 2001; Ingole et al. 2002). Due to their strategic location along the central west coast of India, the importance of all the three harbours is considered to further increase in years to come. Thus, the coastal areas along the central west coast of India are a suitable ecosystem to observe the impact of harbour activities by studying the macrobenthic community.

Although studies have been performed along Mormugao, Karwar and Ratnagiri coast, few biological studies corresponding specifically to the macrobenthic community of the harbour have been carried out. Thus, the present study aims to contribute to the knowledge of the macrobenthos and its potential use as diagnostic tool for assessing the environmental health.

Methods

Study area

Field sampling was conducted at Mormugao, Karwar and Ratnagiri (Fig. 1). The Mormugao harbour is situated near the historic city of Vasco-da-Gama (15°27′48″ N; 73°38′64″ E) along the Goa coast. Mormugao port, with a fine natural harbour is one of the oldest major ports on the west coast of India. The port accounts for about 39% of India's iron ore exported and ranks within the first 10 leading iron ore exporting ports of the world. During the financial year 2003–2004, the port handled 8% of the total traffic handled by all the 12 major port of India. Ratnagiri harbour is situated (17°00′38″ N and 73°15′34″ E) in the Mirya Bay along the Maharashtra coast. Karwar port is situated in north Karnataka (14°50′36″ N and 73°54′55″ E) in the mouth of Kali estuary. The Karwar Harbour is one of the best natural all weather harbour. It has a 355 m long quay for accommodating simultaneous berthing of two ocean-going ships. The harbour is used for loading and unloading of all types of commodities including petroleum products. The water depth in the study area varies from 5 to 40 m. The sediment in the inner harbour was generally dominated by silt and clay whereas; outer harbour has higher content of fine sand.

Sample collection

Sediment samples were collected on board *CRV Sagar Sukti* (SASU-105) in January 2006 using van Veen grab (0.11 m^2). Sub sampling was done with a quadrant (225 cm^2). Two stations were sampled in each harbour. Five grabs were collected from each station at Ratnagiri (Rat 1 and Rat 2) and Karwar (Kar 1 and Kar 2) and triplicate samples from Goa (Goa 1 and Goa 2). Reference station was not taken as the sediment outside the harbour was dominated by sand in all the three harbours. All the samples were sieved on board through a 0.5 mm mesh, and the materials retained were preserved in 5% buffered formalin Rose-bengal solution. In the laboratory, macrofauna was sorted, counted and identified to the

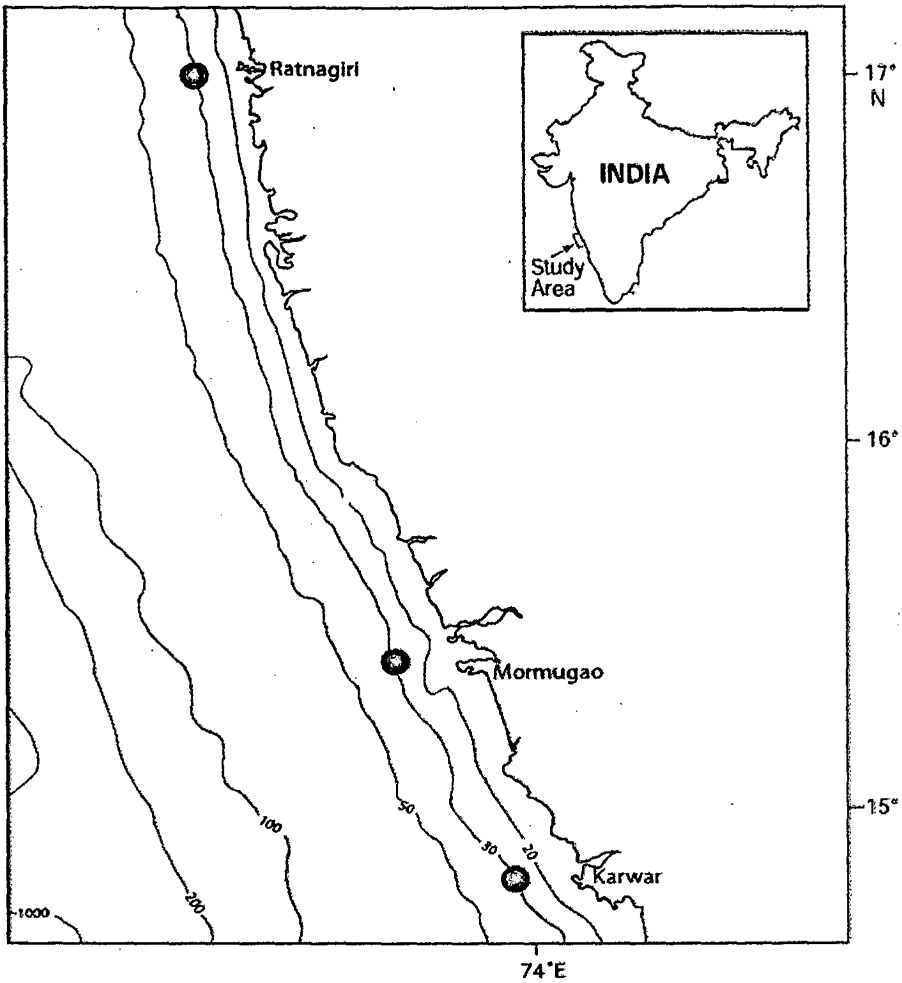

Fig. 1 Map showing the location of the sampling site

lowest possible taxonomic level. Group-wise biomass was measured by wet weight method.

At each station, sediment sample was also taken with acrylic core (ϕ 4.5 cm) for the analysis of sediment chlorophyll, phaeopigment and organic carbon. Chlorophyll *a* (Chl *a*) and phaeopigment were analysed by acetone extraction method (Holm-Hansen 1978) and organic carbon was estimated with CO_2 Coulometer after acidification of sediment to remove the inorganic carbon.

Data analysis

Faunal data was processed using univariate and multivariate methods. Species richness, Shannon–Weiner diversity (H'), Pielou's evenness (J'), Margalef's species richness were calculated using PRIMER (Clarke and Warwick 1994). Multidimensional Scaling (MDS) and Bray–Curtis similarity index was constructed based on macrofauna abundance after log transformation. Following the division into groups from results of cluster analysis, the species having the greatest contribution to this division were determined using similarity percentage program SIMPER. Geometric class and Abundance biomass comparison curve (ABC curve) and the benthic opportunistic polychaete amphipod index (BOPA; Dauvin and Ruellet 2007) were used to determine the environmental status of the study area. The significance of variation of benthic data was tested by analysis of variance (ANOVA). The normality of the data was verified using the Kolmogorov–Smirnov test and the homogeneity of variances using the

Table 1 Macrobenthic species list of the study area (+ present; – absent)

Stations	Rat 1	Rat 2	Goa 1	Goa 2	Kar 1	Kar 2
Echiurida	+	+	–	–	+	+
Sipuncula	–	+	+	–	–	–
Polychaeta						
Family Phyllodocidae						
Phyllodoce sp.	–	+	+	+	–	–
Eteone sp.	–	+	–	–	–	+
Family Aphroditidae						
Sthenelais sp.	–	–	–	+	–	–
Family Syllidae						
Syllis cornuta	–	–	–	+	–	–
Family Pilargiidae						
Ancistrasyllis sp.	+	+	+	–	–	+
Cabira sp.	+	+	–	–	+	+
Pilargidae	–	–	–	–	–	+
Family Nephtyidae						
Nephtys sp.	+	+	+	+	+	–
Family Nereidae						
Nereis sp.	+	+	+	–	–	+
Family Glyceridae						
Glycera alba	+	+	+	–	+	+
Glycera sp.	+	–	–	–	+	+
Family Goniadidae						
Glycinde sp.	–	+	–	–	+	–
Family Cirratulidae						
Tharyx sp.	+	+	+	+	–	–
Family Spionidae						
Prionospio krusadensis	+	–	–	–	–	–
Prionospio pinnata	+	+	+	+	+	+
Prionospio sp.	+	+	+	+	+	+
Family Magelonidae						
Magelona sp.	–	+	–	–	–	–
Family Capitellidae						
Mediomastus sp.	+	+	+	+	+	+
Notomastus sp.	–	+	+	+	+	+
Capitellidae (unidentified)	–	–	–	–	–	+
Family Dorvilleidae						
Dorvillea sp.	+	–	+	+	–	–
Family Lumbrineridae						
Lumbriconereis latereilli	+	+	+	+	+	+
Family Eunicidae						
Eunice sp.	+	–	+	+	–	–
Family Onuphidae						
Onuphis sp.	+	–	+	+	–	–
Family Sternaspidae						
Sternaspis scutata	+	–	–	+	–	–
Family Terebellidae						
Terebella sp	+	–	+	+	–	–
Family Sabellidae						
Jasmineira sp.	+	+	+	+	–	–
Hypsicomus sp.	–	+	–	–	–	–

Table 1 (continued)

Stations	Rat 1	Rat 2	Goa 1	Goa 2	Kar 1	Kar 2
Family Serpulidae						
Hydroides sp	–	+	+	+	+	+
Family Cossuridae						
Cossura sp.	+	+	+	+	+	+
Family Paraonidae						
Aricidea sp.	+	+	+	+	+	+
Levinsenia sp.	+	–	+	+	+	+
Amphipoda						
Family Ampeliscidae						
Ampelisca sp.	+	+	+	+	+	+
Family Hyalidae						
Hyale sp.	+	–	–	–	–	–
Family Haustoriidae						
Urothoe sp.	–	+	–	–	–	–
Family Oedicerotidae						
Synchelidium sp.	+	+	–	–	–	–
Family Liljeborgiidae						
Liljeborgia sp.1	+	+	–	–	+	–
Liljeborgia sp.2	+	+	+	–	–	+
Family Ampithoidae						
Ampithoe sp.	+	–	–	–	–	–
Family Isaeidae						
Isaeidae (unidentified)	+	+	–	–	+	–
Family Caprellidae						
Caprellidae (unidentified)	–	–	+	–	–	–
Family Podoceridae						
Podoceridae (unidentified)	+	–	–	–	–	–
Unidentified Amphipoda	+	–	–	–	+	+
Cumacea	+	+	–	–	+	–
Family Squillidae						
Squilla sp.	+	+	–	–	–	–
Decapoda						
Family Grapsidae						
Varuninae	–	–	–	–	+	+
Brachyurans	–	–	–	–	+	–
Family Penaidae	–	–	+	–	–	–
Gastropoda						
Family Potamididae						
Cerithidae sp.	–	–	–	–	+	–
Bivalvia						
Family Nuculanidae						
Nuculana sp.	–	+	–	–	–	–
Family Lucinidae						
Lucina sp.	–	–	–	–	+	+
Family Tellinidae						
Tellina sp.	+	–	–	–	–	+
Family Veneridae						
Unidentified Bivalvia	+	+	–	–	–	–

Levens' test using STATISTICA 6. When data did not satisfy the assumptions of the parametric tests, the data was log transformed to achieve normality.

Results and discussion

The sediment chl-*a* values ranged from 0.18 to 0.35 $\mu g\ g^{-1}$ with highest values recorded in Mormugao and lowest at Ratnagiri harbour. Sediment organic carbon ranged from 1.4% to 3.5% with highest values in Goa. Since all the three harbours are located in close proximity of highly populated towns, the organic loading in the area may be mainly from the inflow of domestic waste and fishing activities (Ansari et al. 1994; Anon 1996). Moreover, the harbours are located near the mouth region of the estuary, which brings significant amount of organic material from the upper reaches and deposit in the estuary. River flow is considered to be another major source of organic load in harbours (Webber and Kelly 2003).

The macrofaunal community in the present study was comprised of 55 taxa belonging to six phyla (Table 1). Although, the ecological setting as well as water depth in all the three harbour were similar (varying from 5 to 40 m) macrofauna showed significant variation in composition and abundance. The macrobenthic abundance ranged from 1,214 to 5,407 individuals per square meter (6,135 ± 5,045.8; Fig. 2). Stations in Ratnagiri recorded the highest abundance and lowest values were in Goa. The macrobenthic abundance did not show significant variation within the harbour ($p > 0.05$) but differed significantly between the harbours ($p < 0.001$). Biomass (wet wt.) also showed greater variability between the stations and ranged from 0.14 (Goa) to 145.77 g m^{-2} (Karwar). The higher biomass was largely due to the occurrence of bigger sized echiurids, accounting to 85% of the macrofaunal biomass at Karwar. Biomass value shows significant variation within stations ($p < 0.03$), however biomass did not show significant variation between the harbours ($p > 0.05$).

Polychaetes were numerically dominant accounting for 96% of the total macrofauna. Dominance of polychaete worms was as expected for harbour area and compares well with other harbour studies (Raman 1995; Belan 2003; Guerra-García and García-Gómez 2004; Rivero et al. 2005). The density data was subjected to Bray–Curtis cluster analysis and detected three groups (Fig. 3a). Group I consisted of Ratnagiri stations with 66.36% similarity. Goa 1 and Goa 2 (Group II) clustered at 69.73% and third group

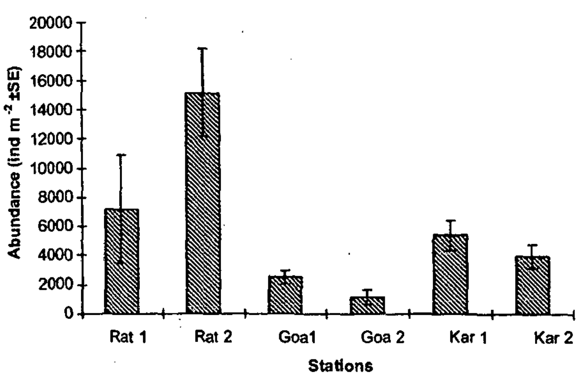

Fig. 2 Comparison of macrofaunal abundance in the harbours

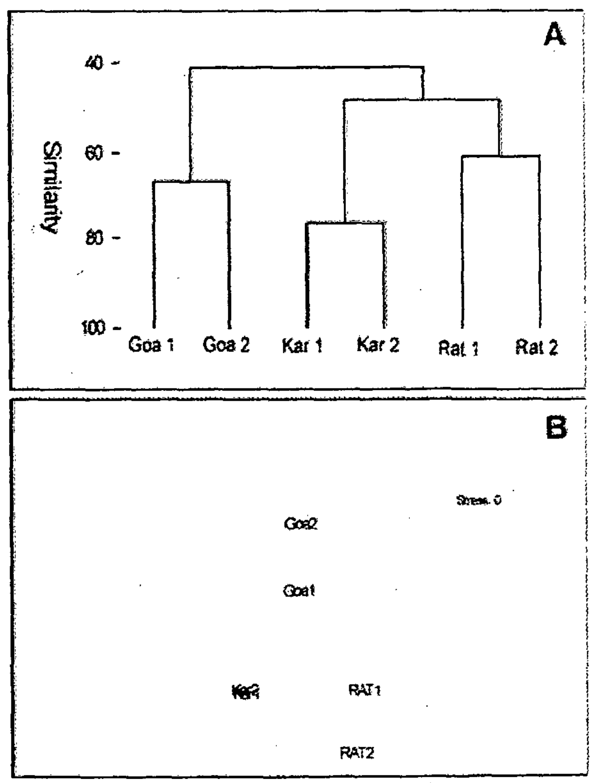

Fig. 3 Cluster and MDS based on macrofaunal abundance

Table 2 SIMPER analysis based on group obtained from cluster and MDS ordination showing the species that contributed to the differences among the groups

Species	Average abundance	Average abundance	Average dissimilarity	Dissimilarity/SD	Contribution %	Cum. %
Group						
Average dissimilarity 78.7	Rat	Goa				
Mediomastus sp.	4,386.72	81.4	30.07	3.71	38.17	38.17
Cossura sp.	1,691.64	111	10.84	2.64	13.76	51.93
Prionospio pinnata	1,900.32	740	8.37	1.64	10.62	62.55
Average dissimilarity 64.0	Rat	Kar				
Mediomastus sp.	4,386.72	492.84	22.05	2.56	34.45	34.45
Notomastus sp.	4.44	1,509.6	9.55	1.8	14.93	49.38
Cossura sp.	1,691.64	279.72	7.86	1.92	12.28	61.66
Average dissimilarity 67.5	Goa	Kar				
Prionospio pinnata	740	2,060.16	20.37	1.93	30.15	30.15
Notomastus sp.	74	1,509.6	20.25	2.11	29.97	60.12
Mediomastus sp.	81.4	492.84	6.26	2.76	9.26	69.38

comprised of Karwar stations (80.24%). MDS ordination confirmed the results of cluster, and detected the same three groups (Fig. 3b). The community data was subjected to SIMPER analysis to find the species, which contributed to the similarity within each group. Accordingly, Ratnagiri was dominated by *Mediomastus* sp. (42.35%), *Prionospio pinnata* (24.76%), *Cossura* sp. (15%); Group II (Goa)—*P. pinnata* (30.88%), *Eunice* sp. (17.65%), *Aricidea* sp. (8.82%); Group III (Karwar)— *P. pinnata* (53.6%), *Notomastus* sp. (21.58%), *Mediomastus* sp. (12%). The species, which resulted in the dissimilarity in the three harbours, are listed in Table 2.

The species composition showed that, the macrobenthic community was represented by fewer species which contributed to >60% of the total abundance (Table 3). *P. pinnata*, *Mediomastus* sp., *Notomastus* sp. of the family Spionidae and Capitellidae dominated. Species belonging to the above families are largely opportunistic and proliferate in sediments with high organic enrichment (Pearson and Rosenberg 1978; Glémarec and Hily 1981). Further, Spionidae and Capitellidae contributed to 20% of the total polychaete species (Table 1). High organic content in sediment can promote the abundance of some tolerant species and reduce sensitive species (Pearson and Rosenberg 1978). *P. pinnata* was the most dominant species at Goa and Karwar, which also showed the highest organic carbon values. *P. pinnata* is a cosmopolitan species occurring in organically rich sediment and in areas subjected to continuous disturbance (Pearson and Rosenberg 1978). In Ratnagiri, *Mediomastus* sp. contributed to 36% of the macrofaunal abundance. *Mediomastus* sp. is

Table 3 Composition (%) of dominant species at various sampling location observed during the present study

Stations	Rat 1	Rat 2	Goa 1	Goa 2	Kar 1	Kar 2
Mediomastus sp.	30.55	41.96	4.66	2.44	8.14	12.77
Prionospio pinnata	17.86	15.91	40.93	25.61	36.46	50.00
Cossura sp.	10.93	16.60	7.25	1.22	6.73	4.33
Notomastus sp.	0.00	0.06	4.66	1.22	38.65	20.13
Aricidea sp.	2.47	2.48	3.11	8.54	0.16	0.65
Prionospio sp.	1.76	16.71	2.07	6.10	1.41	1.95
Eunice sp.	0.47	0.00	6.22	20.73	0.00	0.00
Ampelisca sp.	0.47	0.23	9.33	2.44	0.16	0.22

reported to dominate in areas of moderate disturbance and high energy environment (Rivero et al. 2005). In fact, species belonging to the genus *Mediomastus* sp. flourish in habitat with moderate amount of organic matter with total absence in area of high organic pollution (Pearson and Rosenberg 1978).

The dominance of few species was further confirmed from the geometric abundance curve (Fig. 4). In the geometric abundance curve, the number of species represented by a single individual are in class 1, 2–3 individuals in class 2, 4–7 (class 3), 8–15 (class 4) and so on. In unpolluted situation, the community is represented by rare

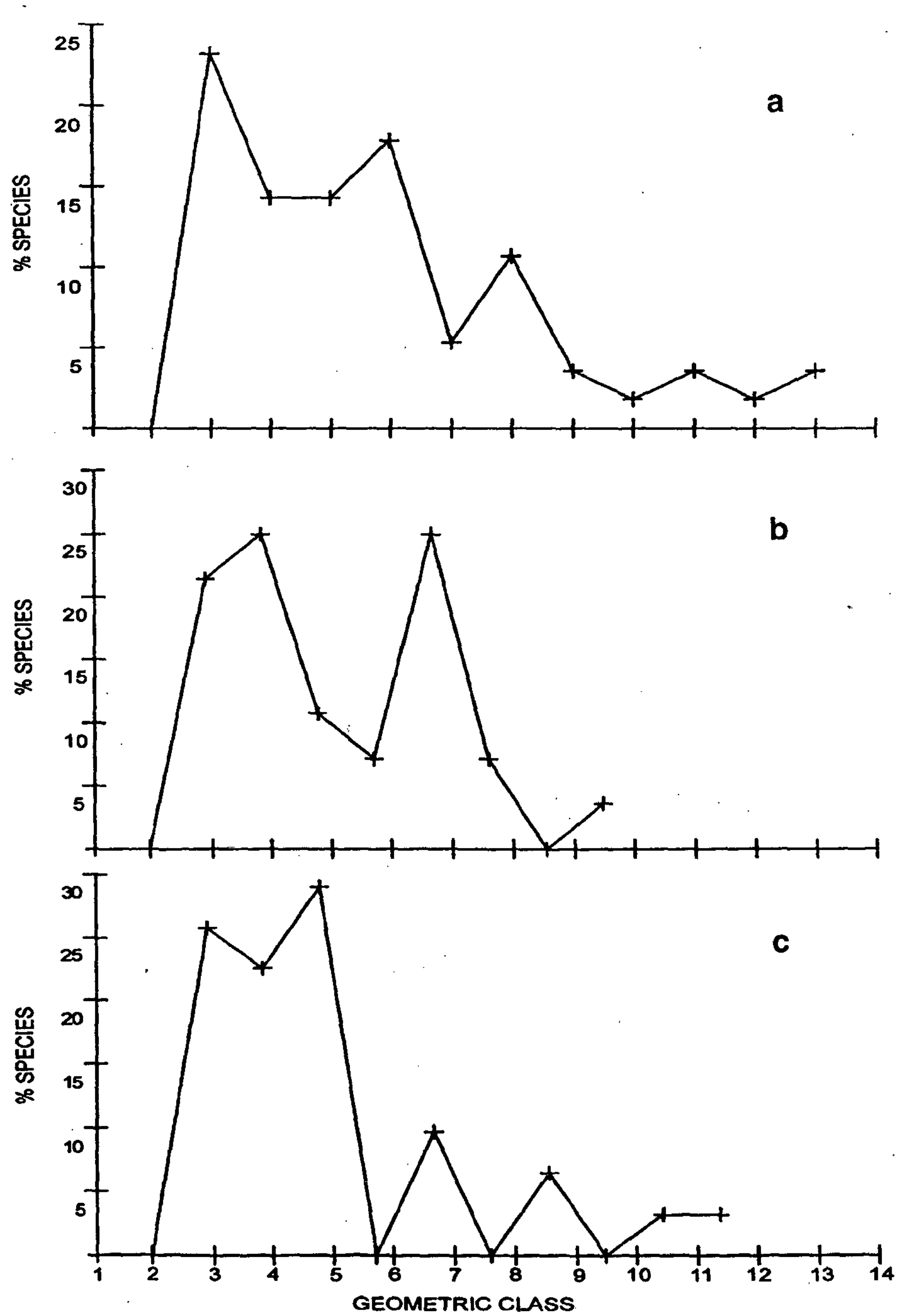

Fig. 4 Geometric class abundance for Ratnagiri (**a**), Goa (**b**) and Karwar (**c**)

species resulting in a smooth curve with its mode to the left. In polluted condition, the community is represented by few rare species and abundance of few species, so that higher geometric abundance classes are more strongly represented and the curve become irregular. In the present study, the geometric abundance curves are very irregular and extend from class 2–13 for Ratnagiri (Fig. 4a) and class 2–10 in Mormugao (Fig. 4b) and to class 2–12 in Karwar (Fig. 4c). Therefore, it can be concluded that the area under investigation was dominated by higher abundance of few species, perhaps resulting from stress conditions due to anthropogenic activities.

Most invertebrate species observed during this investigation were small in size. The possible explanation for the presence of small-sized polychaetes is that the area is frequently disturbed by natural and anthropogenic factors. All the three harbour are located towards the estuarine mouth, an area in the estuary with the strongest hydrodynamics. Further, to maintain required water depth in the harbours, the area is regularly dredged. This may have resulted in the dominance of small, opportunistic, tube-dwelling polychaetes, which are the first faunal components to colonize in disturbed areas (Rhoads and Boyer 1982). A similar association of small sized polychaetes was observed in the northern shallow shelf of Chile and Peru affected by sewage discharge (Carrasco 1997).

Crustaceans were the second dominant group and the community was represented by a total of 16 species (Table 1). The most dominant was the amphipod *Ampelisca* sp., with highest abundance recorded in Mormugao harbour (755 individuals per square meter). In fact, *Ampelisca* sp is known to be dominant in muddy sediments and are well adapted to stress environment (Lowe and Thompson 1997).

The number of species ranged from 21 species (Goa 2) to 36 species at Rat 2. Species richness (*d*) was also highest at Rat 1 (1.7) and lowest at Goa 2 (1.1; Fig. 5). Species diversity (H') was lowest at Kar 1 and Rat 2 (1.4.) and highest at Rat 1 (2.1). Generally, the estuarine communities are subjected to greater natural stress than those in non-polluted coastal waters and are expected to show lower macrobenthic diversity index. Wilhm and

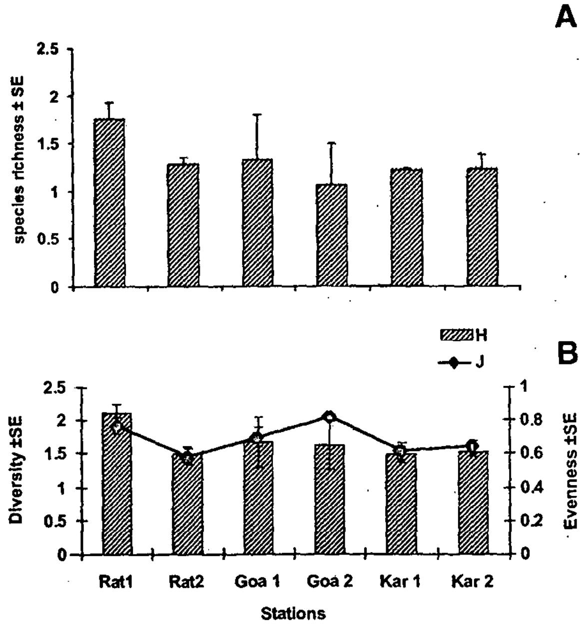

Fig. 5 Comparison of species richness (**a**), evenness and diversity (**b**) between the harbours

Dorris (1966) stated that values <1.0 for diversity index (H') in estuarine waters was common when heavy pollution occurred; values between 1.0 and 3.0 indicated moderate pollution; and values exceeding 3.0 characterized non-polluted water. Diversity value in the study area ranged from 1.6 to 2.4. Thus, clearly indicates that the harbours are polluted and the macrobenthic community is under stress due to natural and/ or anthropogenic factors. Evenness (J) was higher in Goa (0.8) and lower Rat 2 (0.58). The lower J values obtained at Rat 2 were due to the dominance of *Mediomastus* sp., *P. pinnata*, *Prionospio* sp. and *Cossura* sp. together contributed to 91% of the total macrofaunal abundance. Two-way ANOVA showed significant differences in species number and evenness ($p < 0.05$) between the harbours. Within the site, significant differences in species diversity ($p < 0.05$) were however observed only at Ratnagiri.

Various biotic indices have been formulated to study the pollution status of the marine environment. The opportunistic polychaete/amphipod ratio (P/A) based on ecological groups was used in the present study (Dauvin and Ruellet 2007). The P/A ratio ranged from 0.22 in Mormugao to 0.27 in Karwar. P/A values 0 indicate unpolluted condition and 0.3 indicates a grossly polluted condition. The abundance/ biomass comparison (ABC) approach is recommended by Warwick (1986) who stated that, the ABC is suitably an abbreviated descriptor of the state of marine pollution. In certain cases the ABC curve can give wrong picture and can be overcome by the use of partial dominance curve (Warwick and Clarke 1994). In Goa, the abundance curve crossed the biomass curve at several points which was mainly due to the dominance of small sized polychaete species having high density but low biomass (Fig. 6a). The ABC curve showed partial dominance of density over biomass at Ratnagiri (Fig. 6b) and at Karwar the biomass curve dominated over the density curve (Fig. 6c) with crossing at two points. The dominance of biomass curve at Karwar and Ratnagiri was due to the dominance of echiurans that accounted to >80% of the total biomass. The ABC curve is based on the concept that polluted areas are dominated by small-sized species with low biomass. However, dominance of large sized bioindicators, as in the present study can give a "wrong" picture of the pollution status of an area. Echiurans are deposit feeders inhabiting fine-grained, organically rich sediment. Stull et al. (1986) observed that the echiuran worm, *Listriolobus pelodes* reduced the negative effects of wastewater discharge like reducing the pore water hydrogen sulphide and showed high diversity in the coastal shelf region of Palos Verdes, S. California. This was evident from decrease in diversity and increase in opportunistic species of polychaete (*Capitella capitella*) after the decline of the echiuran worm (Stull et al. 1986).

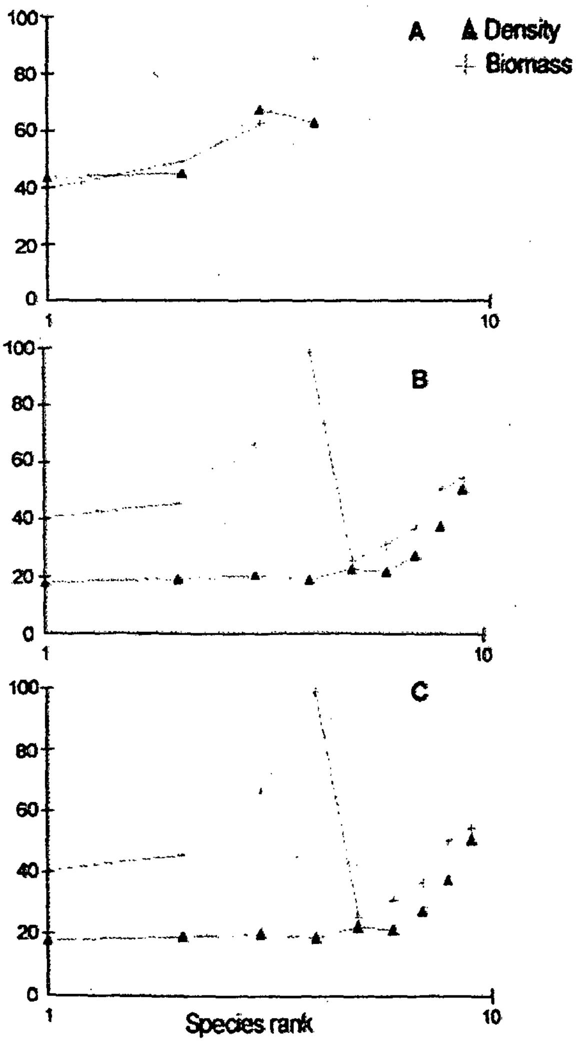

Fig. 6 **a–c** Curve of Goa (**a**), Ratnagiri (**b**) and Karwar (**c**)

The use of biotic indices have often been criticised as many of the indices have given wrong interpretation in areas, which are naturally stressed. Therefore, the combination of indices gave been suggested. In the present study various univariate and multivariate indices were used to detect the degree of pollution. Though all the indices showed a polluted condition the degree of pollution differed. Species richness, abundance of stress tolerant/sensitive species and trophic function and composition were the most successful measurement in differentiating the diversity grade of pollution leading us to think that increase or decrease in the number of tolerant/sensitive species is one of the best disturbance indicator and therefore, essential when it comes to differentiate ecological states. Vincent et al. (2002) observed that the methods combining composition, abundance and sensitivity might be the most promising. Species richness was highest at Ratngairi and was dominated by deposit feeding *Mediomastus* sp. The area also showed the lowest organic carbon content (1.4%). On the other hand, lowest species richness and highest organic carbon were seen at Goa (3.5%) and Karwar (2.8%). Moreover, opportunistic *P. pinnata* dominated the area. The high pollution at Goa and Karwar harbour are expected since the shipping activities are higher compared to Ratnagiri harbour.

The benthic communities are strongly linked to higher trophic levels; therefore any alteration of their trophic structure potentially affects the fishery production of an area. Fisheries in estuarine regions depend more on taxa available at the sediment surface, such as amphipods, mysids, and surface deposit feeders (SDF) polychaetes, than on subsurface deposit feeders (SSDF; Hines et al. 1990; Franz and Tanacredi 1999). Demersal fish constitutes the major portion of the commercial fish landing (particularly the prawns) and any change or alteration in benthic standing stocks will reflect directly in the demersal fish production. Preliminary results of the recent coastal surveys also suggest increasing level of pollution at Ratnagiri, Goa and Karwar (Anon 1996; Nanajkar and Ingole 2007). This along with the increased fishing efforts, over-fishing, may be the main cause for decline in the fishery production of the area (Ansari et al. 2006). Although, macrofaunal abundance was relatively higher at Ratnagiri compared to Goa and Karwar, the fauna was largely comprised of the small-sized, opportunistic annelid species that did not contribute significantly to the benthic biomass.

Continuous assessments of areas under stress, such as harbour, are therefore needed to determine the temporal changes in the community. The long-term monitoring can be time-consuming and expensive. Therefore, the concept of bioindicator should be attempted to use their presence in an area to characterise a certain degree of community change or pollution effects. This approach has been widely applied to benthic monitoring studies and was successfully used in the present study to determine the impact of harbour activities on the marine environment along the central west coast of India.

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