

RESPONSE OF MACROBENTHIC COMMUNITIES TO OIL SPILLS
ALONG GOA COAST

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ABSTRACT

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. Like other states on the west coast of India, Goa coastline also lies along the oil tanker route and since 1994, four spills have been reported. In May 2006, a bulk carrier "MV Ocean Seraya" ran aground along the Karwar Coast and the impact of the slick was also visible 20 kms away in South Goa.

In view of the increased incidents of oil spills, it was felt necessary to analyse and discuss the impact of oil spills on the intertidal benthic community and coastal fishery. The present work also discusses the impact of oil spill from MV Ocean Seraya and the impact of other oil spills on the intertidal macrobenthic community along the Goa coast.

Macrobenthic sampling was carried out at three beaches in South Goa on 10th June 2006. Sediment and water samples were also collected for the analysis of Petroleum Hydrocarbon content (PHC) and Chlorophyll a.

Environmental parameters observed during the present study were in accordance to those recorded normally during the monsoon season. Sediment chlorophyll a, ranged from 0.01-0.03 $\mu\text{g.g}^{-1}$. Total organic carbon ranged from 0.2-1% at Benaulim and Polem, respectively. PHC concentration was highest at Polem ($13\mu\text{g.g}^{-1}$) and lowest value ($2\mu\text{g.g}^{-1}$) was at Agonda.

Average macrobenthic density of 1635, 7499 and 6419 no.m^{-2} recorded at Polem, Agonda and Benaulim, respectively. A total of 20 macrobenthic taxa were identified with highest at Agonda (11 taxa) and lowest at Polem (6 taxa). Margalef's species richness ranged from evenness values (0.3). Shannon-Weiner diversity was highest at mid tide of Agonda (1.5) and lowest at Polem high tide (0.27). Clustering and MDS plot showed that, all the three study areas differ in macrofaunal community as Polychaeta dominated in Polem (59%), Nemertenia (41%) at Agonda and Bivalvia at Benaulim.

Faunal density showed a negative correlation with PHC. PHC concentration at Candolim site where MV River Princess has been grounded was high and showed further increase from 43 to 58 mg.g⁻¹ in 2004. 6-8cm depths showed highest concentration. The macrobenthos community of Candolim when compared to previous data, showed a decrease from 27 species to 11 species and in 2004 only 8 species were observed. The significant increase in sediment PHC, indicating the possibility of long-term impact of oil spills.

Literature shows that the West coast of India is vulnerably exposed to any oil spill only during SW monsoon. Also monsoon is the recruitment period for most benthic organism. As it is evident from the present study that major recruitment of *Emerita* occurs during monsoon as the *Emerita* population was dominated by juveniles (>80%). The effect of oil spills is first observed in the pelagic organism. There is an increasing data of the susceptibility of early developmental stages to oil, at concentrations substantially lower than those inducing morphological changes in juvenile marine organisms.

Oil pollution along with other pollutions is likely to pose significant ecological risk in years to come. Of particular interest is the impact of pollution caused to fisheries and other commercial use of coastal and marine habitats. Most of the important fishery has been damaged due to overexploitation, with the situation becoming aggravated with increase coastal pollution. 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.

CHAPTER 1

Introduction

The Indian Ocean is the third largest of the four major oceans. It covers an area of 74 million sq. km which comprises $\approx 20\%$ of the total area of water in the world. Petroleum is the most significant mineral in the area, which accounts for 28.5% of the total world oil production.

The ocean has been and remains 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 important not only to India, but also to the littoral states of the Indian Ocean that are dependent on the ocean for shipping and transportation. The demand for oil is increasing and the import of crude oil has taken a quantum leap worldwide. Recent study suggests that about 70% of the total sea transport is ferried through Indian waters (Anon, 2003). Moreover Asia's largest ship breaking yard Alang is also located along the west coast of India.

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 oil pollution. Immediate steps, therefore, are required to deal with the consequences.

In the present study, attempts are made to identify the problems related to oil pollution. Further, the possible impact of oil spills on beach fauna is explained with case studies.

The Indian Coast

India has a vast coastline of 7500 km along the mainland in addition to that of the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep Islands in the Arabian Sea (Nayak, 2005). The Indian coast has a large variety of sensitive ecosystems like lagoons, sand dunes, coral reefs, mangroves, sea grass beds and wetlands (Ingole, 2005). These coastal habitats are considered highly productive in terms of biological production. Some of these areas act as spawning and nursery

grounds for commercially important fishes, molluscs, crustaceans and various other species that constitute the coastal fisheries.

Intertidal Zone

The intertidal zone is the area between low and high water marks. This is a zone of interaction between the sea, land and air, which is one of the most interesting regions of the marine environment. Organisms that live in the intertidal zone frequently need to deal with changing environmental extremes and are known to be hardy and diverse. Intertidal animals experience extreme physiological stress during the low tide period and those species inhabiting the upper intertidal zone are often more tolerant of thermal and desiccation stress than those found in other zones (McMahon, 1990; Sokolova *et al.*, 2000). The intertidal zone is an astonishing glimpse at the food chains, interactive life cycles, and many special adaptations to this difficult environment. This zone is considered as the most productive with the greatest diversity of life of any ecological area of the world.

Zonation in the intertidal environment

Throughout the intertidal area, a very fascinating phenomenon known as zonation occurs. Zonation is the vertical banding of the organisms. These distinct bands occur in part from many complex physical and biological factors that effect marine organisms. The zonation of organism along altitudinal, latitudinal or intertidal gradients is a reflection of their response to both physical and biological factor (Whittaker, 1975; Parulekar, 1981; Mettam, 1994). Harsh environmental factors such as thrashing waves and temperature stress from exposure all contribute to the formation of this phenomenon. Zonation is not, however, entirely the result of adaptation to physical conditions. There are biological factors, especially competition and predation that have to be considered (Tamaki *et al.*1997). If a particular predator for instance, can live comfortably at certain tides levels than the population of a species on which it feeds will be kept in check (Tamaki *et al.*1992b). If the prey species can flourish at higher levels than the predator can, then it may become abundant at those levels. Distribution of

intertidal animals is usually stratified along the vertical gradient of the littoral zone (Newell, 1979; Underwood, 1979).

The Benthic Community

Organisms that habitually live in or near the seabed at any time during their life history constitute the benthos. The benthic community is composed of a wide range of flora, fauna and bacteria from all levels of the food web. Benthic organisms live in a two-dimensional world, quite unlike the three-dimensional world of the planktonic and nektonic organisms. The three benthic life strategies are (1) sessile: attachment to firm surfaces (2) mobile: free movement of the bottom or (3) burrower: burrowing in sediments. These life styles correspond to the principle ways of obtaining food among benthic organisms: filtering from seawater, predation or swallowing and digesting sediments. Benthic organisms must compete for living space as well as food.

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.

Classification of Benthos:

Based on position

The benthos is normally divided into three functional groups, the infauna, epibenthos and hyper-benthos.

- **Infauna:** Plants, animals and bacteria of any size that live in the sediment.
- **Epifauna:** Plants, animals and bacteria that are attached to the hard bottom or substrate (for example, to rocks or debris); are capable of movement; or that live on the sediment surface.
- **Hyper-benthos:** those organisms living just above the sediment.

Based on Size:

Benthos are classified into 3 categories:

Microfauna: Those organisms having size between 1-50 μm (e.g. bacteria, protozoan, protophytes). Their metabolic activities largely control the chemical nature of sedimentary environment. Bacteria accounts for more than 50% of the metabolism of benthic communities. In general, microorganisms are responsible for over 95% of community respiration (Fenchal, 1967).

Meiofauna: Benthic animals having body size between 50-500 μm (foraminiferans, copepods, nematodes, turbellarians, several larval forms). Micro flora and fauna form major source of food for the meiofaunal communities although they use selectively the dissolved organic compounds to synthesize carbon. About 16- 20% of the meiofaunal production is utilized by macrofauna and rest is available for the mobile carnivores like birds, fishes and crabs etc.

Macrofauna: Those organisms having body size $> 500 \mu\text{m}$ (Holm and McIntyre, 1971) are called macrofauna (all macroinvertebrates, macrophytes and selected vertebrates like fish). It mainly constitutes 3 modes of feeding such as filter feeders (bivalves, sponges, ascidians, worms, barnacles), browsers (amphipods, isopods, gastropods etc) and deposit feeders (annelids, bivalves, gastropods, holothurians, crustaceans etc.). They prefer hard bottom and silty sand rather than muddy bottom.

Megafauna: Megafauna are defined as organisms large enough to determine on photographs or trawl caught organisms more than 3-cm stretch mesh (Rowe, 1983). They have low densities, and are too mobile and hence the usual benthic samplings gears do not sample them adequately. They play a key role in the abyssal ecosystem (Smith & Hamilton, 1983) because they comprise a major proportion of the deep-sea biomass, playing a key role in the transfer of organic matter.

Significance of Benthos

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 larger organism, especially the demersal fishes. (Philip, 1998; Olaso et al, 2000; Takai et al, 2002; Ingole, 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 (such as polychaetes and nematodes). The nutrients released from the sediment due to bacterial degradation of organic matter diffuse and disperse fairly 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 organism of economical importance, variety of migratory and resident birds, fishes, sea mammals and reptiles.

Benthos as 'bioturbators'

The sediment reworking by the benthic organisms is also known as "Bioturbation". The movements of benthic organisms create bioturbation during their movements and feeding activities, which condition the sediments for meiofauna and microfauna and as a stimulant of nutrient regeneration. Bioturbation increases oxygenation and mineralization (Hines and Jones, 1985; Kristensen et al, 1985; Tamaki & 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 (Waslenchuk et al., 1983; Marinelli, 1992; Ingole et al., 2005).

Benthos as bioindicators

Benthic invertebrate are among the most common organisms used in biological monitoring, for their:

- (1) high species richness with a variety of life history patterns and tolerances to habitat disturbances;
- (2) majority of the species are sedimentary;
- (3) Their responses integrate water and sediment quality changes;
- (4) Some species have relatively long life spans;
- (5) They are the key elements in the food web of aquatic systems and affect chemical fluxes between sediments and water column.

The benthos reflects the effects of pollutants by responding through detectable changes in population dynamics on a time scale of weeks to years. This is in contrast to plankton, which shows a more immediate change to point sources with no long-term consequences to the populations (Gray et al, 1992). Benthic monitoring is also a relatively sensitive, effective and reliable technique that can detect subtle changes that serve as an early indicator before more drastic environmental changes occur. Thus, benthos plays a major part in the strategy of biodiversity conservation. Studying the benthos is also useful in understanding changes in biological diversity.

Marine Oil Pollution

Pollution of marine waters was realized somewhere in the 1970s. It was otherwise thought that the world's oceans have an infinite capacity for absorbing our toxic wastes. Some major types of pollutants that have been the focus of recent research are oil, sewage, garbage, chemicals, radioactive waste and thermal pollution. Among these, oil

pollution is always discussed at length because other pollutants affect limited areas; except of course radioactive pollution.

Sources of oil pollution

Drilling, transport, and burning have all led to addition of oil to marine environments.

The following are the major sources of oil pollution:-

- Leaks from marine terminals and harbors.
- Leaks from offshore and nearshore drilling and refineries
- Leaks from accidental breakup of oil tankers and barges
- Deliberate washing of oil tankers in the open sea
- Washout of oil from settled areas into storm drains and direct washout to the shoreline.
- Ship breaking yards, ships anchored at harbours and jetties and water sports facilities on popular beaches.
- Natural seepage from sea bed.

Oil pollution is important to the Indian coastline, because, most of the petroleum products (including oil) originate in the West Asian countries is transported from the Indian Ocean to other parts of the world.

Although, currently, India has only 0.4% of the world's proven reserves of hydrocarbons, however, there are indications of large depositions of hydrocarbon and gas hydrates in the deeper continental margin. 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), but an offshore gathering platform at the field was damaged in a fire in July 2005. India's average oil production level (total liquids) for 2005 was 837,000 bbl/d, of which 632,000 bbl/d was crude oil. India had net oil imports of nearly 1.7 million bbl/d in 2005. Future oil consumption in India is expected to show strong growth, to 3.1 million bbl/d by 2010, from 2.5 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.

The shipping routes, through which the crude oil reaches the countries importing them from West Asia, pass through the straits of Hormuz located in Oman/Iran, which connects the Persian Gulf of Oman and the Arabian Sea. Oil destined for Japan, United States and West Europe also takes this route. The Hormuz strait is by far the world's most important **oil choke point**. This is followed by the Strait of Malacca, which connects the Indian Ocean with the South China Sea and is close to the Andaman Sea.

Oil bound for Japan, South Korea, China and other Pacific rim countries passes through this strait. The Bab-el-Mandab, located in Djibouti/Eritrea/Yemen, connects the Red Sea with the Gulf of Aden and the Arabian Sea, from where oil is exported to destinations in Europe, the United States and Asia. This is another **choke point**. Due to the narrowness of these lanes, routes are accident-prone (Fig 1.1). An accident even to one of these very large crude carriers could spill up to 100,000 tonnes of oil on the Indian coastline.

Environmental Impact of Oil Spills

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. As the oil enters into sea it is exposed to processes, which modify it both physically and chemically. This process is called weathering. As the oil tends to float on the surface of sea, the prevailing wind, wave, tide and current conditions make the oil to spread to a wider spectrum of area from the point of release. If wave action is sufficiently intense, the oil may also be mixed to some depth in the water column, where sensitive organisms are exposed and injured. It was during this first phase of the '**Exxon Valdez**' oil spill that most of the recorded mortality of seabirds and marine mammals occurred (Piatt & Lensink, 1989). The majority of crude oil forms sticky layers on the surface, which prevents free diffusion of gasses, clogs adult organisms feeding structures and decreases the sunlight available for photosynthesis. Volatile components of an oil spill

eventually evaporate into the air, leaving heavier tars behind which form tar balls, which fall to the bottom and may be assimilated by bottom organisms or incorporated into sediments. 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 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. 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 gets 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.

The vulnerability of inshore 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 rock 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 (Plate 1.1 A) and the inability of organisms to adhere to there substrate (Newey 1995).

Roberts (1976) showed that mussels exposed sub-lethal concentrations of oil were able to survive and elute 80-90% after being exposed to clean saltwater. Other organisms such as limpets, periwinkles, topshells, and barnacles do show increased mortality and population declines under increased oil content (Simpson et.al. 1995, Newey and Seed 1995).

Seabirds are the most conspicuous marine organisms and have been used as monitors of the marine environment (Montevecchi, 1993, 2001) and of the incidence of oil pollution for decades (Furness and Camphuysen, 1997). Oil at sea is a threat to seabirds because it forms a thin layer on the ocean surface where many birds spend most of their time (Plate 1.1 B). The hydrophobic nature of oil causes plumage to readily absorb the oil, which decreases the bird's insulation, waterproofing and buoyancy, leading to death due to hypothermia or starvation (Brown, 1990). The many toxic compounds in the oil, when ingested or inhaled while preening, can also lead to debilitating or fatal effects due to their impact on internal organs (Fry and Lowenstine, 1985; Leighton, 1993; Briggs et al., 1997). The amount of oil that is lethal to birds is very small (Khan and Ryan, 1991; Leighton, 1995). Based on the frequent overlap of shipping activities and seabird distribution, it is not surprising that beached bird surveys around the world have reported dead and live oiled seabirds resulting from chronic spills for decades (Camphuysen, 1989, 1998; Auerbeck et al., 1992; Ravel, 1990; Vaitakus et al., 1994; Zydalis, 1997; Wiese and Ryan, 1999.). It has been suggested that these chronic effects may be as important or more important to long-term seabird population stability than occasional large spills (Hunt, 1987; Burger, 1992). It is rather the timing and location of the spill that determines the degree of seabird mortality (Burger, 1993b). Moreover, there is experimental evidence that small amounts of oil transferred to eggs by sub-lethally oiled adults can significantly reduce hatching success. Worst case scenarios would include oil impacting feeding grounds at a time when large numbers of migratory waders or sea ducks are in the area.

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 (Plate 1.2). Species at particular risk are those which rely on fur for conservation of body heat (e.g. otters). If the fur becomes matted with oil, they rapidly lose heat and die of hypothermia. Whales, dolphins and seals are at less risk because they have a layer of insulating blubber under their skin.

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. Major impacts of oil spills on fisheries and aquaculture are the smearing of nets and fish cages and the tainting of fish and shellfish, rendering them unfit for marketing. As compared to adult, which can avoid contaminated areas, the early developmental stages such as eggs, larvae and juvenile fish, to oil in surface waters, is at higher risk.

In addition to ecological concerns, shoreline spills can affect the air quality, due to the hydrocarbon gases and sulphur compounds present in the oil, and are also a potential fire hazard. They will also depress recreational areas, harbours, industries, commercial fishing grounds and tourist attractions.

Objective of the study

- To study the impact of oil spill from the MV Ocean Seraya on the intertidal macrobenthic communities of South Goa.
- To study the behaviour of most dominant macrobenthic species (*Emerita holthuisi*).
- To predict possible impacts of increasing oil spills incidents on the benthic communities along the Goa coast.

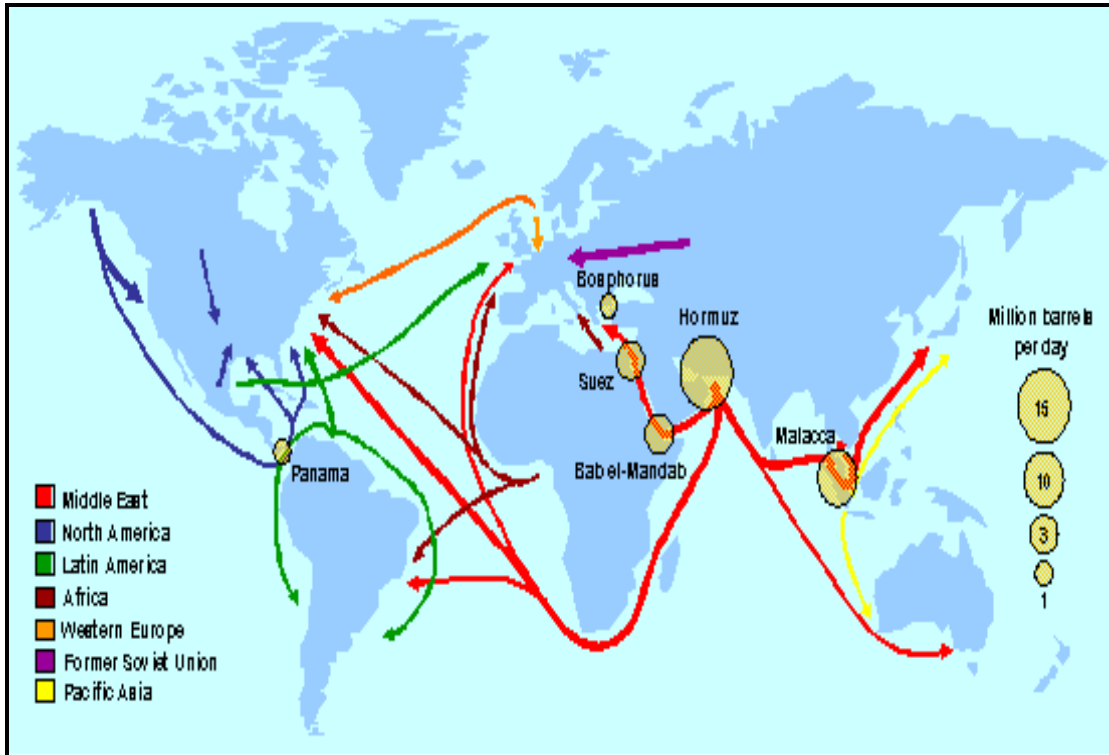


Fig 1.1 Major oil routes and oil choke points of the world.

(Source:-www.people.hofstra.edu)

PLATE 1.1

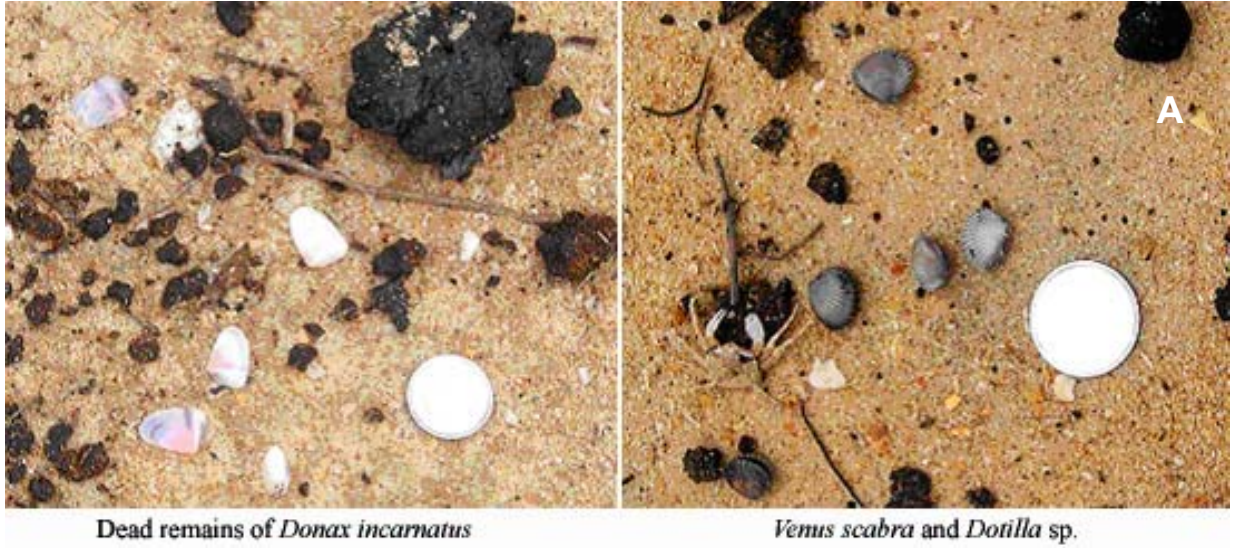


Plate 1.1 A: Effect of oil spills on intertidal benthic community



Plate 1.1 B: Effect of oil spills on sea birds

PLATE 1.2



Plate 1.2: Effect of oil spills on sea otters (Exxon Valdez oil spill)

CHAPTER 2

LITERATURE REVIEW

Pollution, urbanization, and human population growth are increasing along tropical coastlines at an alarming rate (Hatcher et al., 1989). These factors alone necessitate a review of the widely scattered, tropical benthic literature, not to mention the probable harm to advances in benthic ecology, if this information continues to be ignored (Alongi, 1990).

Intertidal benthic ecology:

Sandy beaches are distributed worldwide, having ample spectrum of sizes, morphologies, exposure ranges and oceanographic conditions together with high diversity and biotic characteristics. The most dynamic soft bottom habitats (McLachlan et al., 1996) exposed sandy beaches occurs on the open coast of tropical and temperate regions (Davies, 1972). They are important, sensitive and widespread coastal habitats. Sandy beaches are important coastal ecosystems; provide shelter to diverse taxonomic groups that form considerable links in the marine food web (Feder & Jewett, 1981; Brown & McLachlan, 1990). Compared to tropics extensive research has been done on the temperate intertidal ecology (Alongi, 1990).

The review of the recent literature suggested that even though intertidal ecological investigations in India were initiated as early as in 1960's review of world-wide literature suggest that when compared with other tropical beaches, limited research has been carried on the Indian beaches. The ecology of sandy beaches with special reference to macrobenthic populations along the Indian coasts has been studied in early 60's Govindankutty *et al* (1966) and the influence of physical and chemical factors on the production of macrofauna. McIntyre (1968) has reported meiofauna and macrofauna inhabiting the beaches near the Porto Novo on the east coast. Seasonal changes in physico-chemical factors and some biological details of common intertidal populations have been studied at Cochin, Shertalli and Goa beaches (Ansell *et al.*, 1972; McLusky

et al., 1975). Achuthankutty (1976) studied the sandy beach ecology at Sancoale, Goa. Some of the above workers discussed the physical factors limiting the biological production on the sandy beaches, especially during the monsoon season. *Emerita holothuisi* is dominant fauna in Sancoale with June and July being the main recruitment period (Achuthankutty & Wafar, 1976). Achuthankutty *et al* (1978) studied the ecology and production of sandy beach at Baina, Goa. They observed the stability of the beach substratum influences to a very great extent the production of sandy beaches. Nair (1978) studied the species composition, biomass and available food of the intertidal fauna at Goa and suggested that fluctuation in the production of macrofauna was related to environmental stress and availability of food. Quantitative studies on the intertidal benthic macrofauna of Sagar Island, Sunderbans, were carried out by Nandi and Choudhary, (1983). Ansari and Ingole (1983) studied the meiofauna of some intertidal sandy beaches of Andaman Islands. Rodrigues (1984) studied on community structure of the intertidal fauna at Dona Paula beach Goa. Harkantra and Parulekar (1985) studied the ecology of two sandy beaches of Goa along the western coast of India and revealed the presence of 47 macroinvertebrates belonging to 32 families. Harkantra and Parulekar (1985) studied community structure of sand-dwelling macrofauna of an estuarine beach in Goa and suggested that community indices increased from high water to low water mark. Fernando (1987) studied the composition and distribution of macro- and meiofauna at the marine, gradient and tidal zones in relation to seasons and tide levels from the intertidal region of Vellar estuary. Goswami (1992) reported 119 intertidal organisms from Digha coast, West Bengal. Rivonker and Sangodkar (1997) described the benthic production in terms of macrofaunal density, biomass (dry weight) and production along Agatti, Kalpeni and Kavaratti atolls of Lakshadweep in relation with physico-chemical parameters. Ingole *et al* (1998) studied the population characteristics of mole crab from Kavaratti beach at Lakshadweep. While discussing the relationship between the intertidal meiofauna and environmental variables Ingole and Parulekar (1998) suggested that salinity is the key factor structuring the meiofaunal community structure of Siridao beach at Goa. Modassir (2000) studied the qualitative and quantitative changes in the intertidal fauna of Miramar beach, Goa. Kulkarni *et al* (2000) studied the Neritidae (Gastropoda) in the

intertidal region of Mumbai and reported that in spite of tremendous pollution stress on the intertidal region of Mumbai, many parts of this region are still crowded by diversified molluscan fauna. Ingole (2003) described the macrobenthic community and rate of sediment reworking on Miramar beach of Goa. Sivadas et al (2005) investigated the intertidal macrobenthic community at Kalabadevi beach and suggested marked zonation on this economically important sandy beach. Impact of oil pollution from grounded bulk carrier on the intertidal beach communities at Goa has been described in detail by Ansari and Ingole (2002) and Ingole et al (2006).

Oil Spills and Marine Environment:

List of Major Oil Spills of the World given in Table: 2.1.

***Torrey Canyon* (1967):**

The wreck of the tanker ***Torrey Canyon*** off the English coast in 1967 was the first oil spill that awakened the international community to the dangers of oil transport. In a few days after the ship cracked up on the rocks, 80 tonnes of crude oil was released. The remaining 40 tonnes burned after the Royal Air Force made a bombing run over the site. Both oil and detergents devastated seabirds and shore invertebrates. It was clear that tanker accidents could have a devastating effect on marine life (Smith, 1968).

***Amoco Cadiz* (1978):**

The tanker ***Amoco Cadiz*** ran aground off the coast of Brittany on 16 March 1978 following a steering gear failure. The entire cargo of 223,000 tonnes of light crude oil and 4,000 tonnes of bunker fuel was released into the seas. Much of the oil quickly formed a viscous water-in-oil emulsion, increasing the volume of pollutant by up to five times. The incident resulted in the largest loss of marine life ever recorded after an oil spill. Two weeks after the accident, millions of dead molluscs, sea urchins and other benthic species washed ashore. Cleanup activities on rocky shores, such as pressure-washing, as well as trampling and sediment removal on salt marshes caused biological impacts. Whilst rocky shores recovered relatively quickly, the salt marshes took many years. Failure to remove oil from temporary oil collection pits on some soft sediment

shorelines before inundation by the incoming tide also resulted in longer-term contamination. In the case of the **Amoco Cadiz** spill on the Brittany coast, benthic populations eventually recovered (Chassé 1978). It is not clear how fast recovery will be in the colder waters of Alaska and Antarctica, where oil breakdown may be slower (Chassé 1978).

Exxon Valdez (1989):

In March 1989, the tanker **Exxon Valdez** hit a reef in Prince William Sound, Alaska, and spilled about 37,000 tonnes of oil, the worst spill in US history. Thousands of marine animals and seabirds were killed, and hundreds of miles of shoreline were covered with oil. The cleanup probably did more damage to rocky shore communities than the oil spill itself, but toxic substances from the oil still remain in sediments and had a negative impact on anadromous fish production for several years after the spill. (Peterson, 2001)

Braer (1993):

The oil tanker **Braer** ran aground at Garth's Ness on the southern Shetland Isles coast on 5th January 1993 spilling approximately 85 000 t of crude oil and 500 t of heavy fuel oil. Following the wreck of the oil tanker **Braer**, a study of the benthic fauna in areas of sea-bed contaminated by oil was carried out (Kingston, et al.,1995). The results showed that no significant changes in benthic community structure, as characterized by species richness, individual abundance and diversity could be related to the areas of seabed affected by the **Braer** oil spill. However, the levels of petroleum hydrocarbons in the most heavily contaminated sediments were sufficiently high to have eliminated sensitive groups such as the Amphipoda and encourage species associated with oil pollution.

Prestige (2002):

On 13th September 2002, the oil tanker **Prestige** sunk off the Galician coast, which affected the entire coastline, particularly the exposed rocky shores and sandy beaches of Spain (de la Huz et al., 2005). A decrease in the species richness was generally

observed in all the studied beaches, with the most affected beaches lost up to 66.7% of the total species richness after the oil spill.

Two years after the ***Prestige oil spill*** (POS) an assessment of the effects on benthic fauna was carried out which showed no significant correlations between tar aggregates and species richness, biomass and diversity of benthic communities. Nevertheless, a decrease in the densities of several epibenthic indicators was detected the first year after spill, followed by a noteworthy recovery in 2004 (Serrano et al., 2006).

Tasman Spirit (2003):

The oil tanker ***Tasman Spirit*** grounded in the channel of the port of Karachi, on 27, July 2003 carrying a cargo of 67,535 tonnes of Light crude oil. Approximately 30, 000 tonnes oil spilled when the ***Tasman Spirit*** broke down. Initial assessment carried out in the Clifton beach did not have the same abundance of polychaete worms and clams as has been observed in other occasions before the oil spill. Star fish (*Astropecten sp.*) were found alive on the beach but they were sluggish in movement. Gastropod (*Tona sp*), live hermit crabs, spider crabs, and fishes (Mulletts) were observed to be coated with oil (Anon, 2003).

Gulf War

During the Gulf War in January 1991, 10,00,000 tonnes of oil spilled into the sea offshore Kuwait and Iraq at the head of the Gulf between January and May 1991, and a minimum of nearly 16 billion (100 million barrels) of crude oil were burned or spilled at the 702 sabotaged oil wellheads in Kuwait's terrestrial oil-fields between February and November 1991. The resulting oil and smoke pollution affected mainly Kuwait and Saudi Arabia: comprehensively oiling about 560 km of the intertidal zone there (about half of the mainland coast), as well as the shores of two offshore islands (Karan and Jana). Biogeographically populations of four seabird species suffered severe mortality (22-50%), and the intertidal flats of the Saudi Arabian Gulf coast, a globally important feeding and re-fuelling area for migratory wader *Charadrii* populations, were severely polluted with a consequent drastic reduction in the number of water birds supported by this habitat (Evans et al., 1993).

LEBANON (2006)

The spill came after Israeli planes struck a Lebanese Jiyeh power plant, about 25 miles (40 kilometers) south of Beirut. The plant's damaged storage tanks leaked 20,000 to 30,000 tonnes of oil into the eastern Mediterranean Sea, the oil slick covered 170 km of coastline, and was threatening Turkey and Cyprus. The oil covering its rocky coasts killed algae and other organisms that fish and turtles feed on.

The slick reportedly caused breathing problems, killing fish, and threatened the habitat of the endangered green sea turtle. Rare monk seals, which have been observed in the past in the reserve's waters, might be affected as well. They are listed as critically endangered on the IUCN Red List of Threatened Species. It may take at least 10 years to recover from this spill. (www.nationalgeographic.com, www.iucn.org)

OIL POLLUTION IN INDIAN WATERS

Studies on the effect of oil pollution along the Indian Coast are limited. Nair *et al.* (1972) studied the tar ball distribution in 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 off Arabian Sea is more polluted compared to the east coast on account of the heavy transportation of crude oil by tankers from the Middle East oil fields to the South East Asia and Far East (Ramamurthy & Sreenivasan, 1983). Similarly, the deposition of tarballs in the beaches of west coast of India was found to

be on higher side when compared to East Coast of India (Ramamurthy & Sreenivasan, 1983).

In case of large spill caused by '*Cosmos Pioneer*' disaster on 18th 1973 in North west coast of India and '*Trans Huron*' disaster in south west coast of India (when) resulted in heavy kill of organisms and resettlement of the sediments by the original (Nammalvar & Ramamurthy, 1976). Many marine creatures ranging from fish, crustaceans, echinoderms response to chemical stimuli due to tar ball deposition that trigger numerous kinds of behavioral response including feeding, preening movement display and many others (Ramamurthy & Sreenivasan, 1983)

Fondekar et al (1980) studied the distribution of PHC in coastal waters of Goa with average PHC value in water and sediment were 30.9 μ g/l and 7.1 μ g/g dry weight, respectively. The ore carrier "*MV Sea Transporter*" carrying 1000 tonnes of fuel oil grounded a few meters from Sinqerim beach of Goa in June 1994. Short and long term effects of a fuel oil spill on meiofauna were investigated by Ansari & Ingole (2002). A significant reduction in the absolute abundance of meiofauna was observed immediately after spillage, particularly at Sinqerim beach, the site of spillage. Long-term response showed no apparent oil induced changes at major taxa levels. The ecotoxicological effects of oil spill from the grounded ore carrier "*MV River Princess*" on the intertidal benthic organism of Sinqerim-Candolim was investigated by Ingole et al, (2006). The vessel carrying approximately 65 tonnes of oil ran aground in June 2000 along the Sinqerim-Candolim- Calngute beach. 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 Aug.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.

Table 2.1: Major Oil Spills of the World (1967- 2003)					
Sr.no.	Ship name	Year	Location	Oil lost (tonnes)	Effects
1.	Atlantic Empress	1979	Off Tobago, West Indies.	287,000	
2.	ABT Summer	1991	Off Angola.	260,000	
3.	Castillo do Beliver	1983	Off Saldanha Bay, S.Africa	252,000	Negligible impact on fish
4.	Amoco Cadiz	1978	Off Brittany, France	223,000	benthic fish, invertebrates & birds.
5.	Haven	1991	Genoa, Italy	144,000	
6.	Odyssey	1988	Off Nova Scotia, Canada.	132,000	
7.	Torrey Canyon	1967	Scilly Isles, UK	119,000	Shoreline, seabirds.
8.	Urquiola	1976	La Coruna, Spain	100,000	
9.	Hawaiian Patriot	1977	Honolulu	95,000	
10.	Independenta	1979	Bosphorus, Turkey	95,000	
11.	Jakob Maersk	1975	Oporto, Portugal	88,000	
12.	Braer	1993	Shetland Is, UK	85,000	Benthic fish, shellfish, birds.
13.	Khark 5	1989	off Atlantic coast of Morocco	80,000	
14.	Aegean Sea	1992	La Coruna, Spain	74,000	
15.	Sea Empress	1996	Milford Haven, UK	72,000	Bivalves, algae.
16.	Katina P	1992	Off Maputo, Mozambique	72,000	
17.	Prestige	2002	Seas off Northern Spain	63,000	Beach, fishery.
18.	Assimi	1983	Off Muscat, Oman.	53,000	
19.	Metula	1974	Magellan Straits, Chile	50,000	Shores, birds.
20.	Wafra	1971	Off Cape Agulhas, S.Africa	40,000	
21.	Exxon Valdez	1989	Prince William Sound, Alaska.	37,000	fish, sea mammals, invertebrates, birds
22.	Tasman Spirit	2003	Karachi Port, Pakistan	30,000	Beach.
23.	Argo Merchant	1976	Nantucket Shoals, Massachusetts	28,000	Birds.
24.	Erika	1999	coast of Brittany, France	20,000	Echinoderms, foraminiferans.
25.	Tanio	1980	Brittany, France	13,500	Birds, shell fishery, intertidal fauna.

Source: International Tanker Owners Pollution Federation (ITOPF), 2005

CHAPTER 3

MATERIALS & METHODS

MV Ocean Seraya, a Panamanian flag bulk carrier drifted and ran over submerged rocks off Karwar on 30th May 2006 (Plate 3.1A) and later broke into two parts (plate 3.1B). The ship arrived from Karachi in ballast reportedly carrying 650 tonnes of fuel oil and 40 tonnes of diesel. Coast Guard helicopter whilst on surveillance reported oil slick extending 5 nautical miles from the grounded vessel, which eventually reached the Karwar and south Goa coast.

The Coast Guard launched pollution response operation to combat the oil spill. Around 500 ltrs Oil Spill Dispersant (OSD) were sprayed over the spill area. Indian Coast Guard ships with specialized pollution response equipment also reached the area for coordinating pollution response efforts. Around 1000 meters of boom was laid on the northern side of the vessel, 500 meters of boom at low water line off Tagore beach and 200 mtrs of shoreline was barricaded by sand bags by Coast Guard with the help of the local administration. Coconut coir was also laid on one km stretch of Devbaugh beach to act as absorbent. The oil slick extended in north south direction away from coast with streak 4 miles long and approx 100 mts wide. The prevailing weather broke up the slick and reduced the extent of spread with oil disintegrating. Patches of oil slick were reported on shoreline of Karwar.

On 2nd June 2006 the oil spill touched Polem beach on the Goa-Karnataka border. The impact of the slick was also visible more than 20 kilometres away in south Goa at Palolem and Canacona. The westerly winds and strong waves forced the spill towards Goa.

Therefore, the present study was carried out to assess the damage, if any, on the benthic community of the intertidal beaches (Polem, Agonda and Benaulim) along the south Goa. (<http://indiancoastguard.nic.in/>)

STUDY AREA:

Polem (long. 74° 4'E; lat. 14°54'N) and Agonda (long. 73° 59'E; lat. 15°2'N; Plate 3.2 A) are situated in southern most part of Goa (Fig. 3.1). Benaulim (long. 73° 50'E; lat. 15° 15' N; Plate 3.2 B) forms a part of a long stretch of shallow sandy beaches interrupted by Mandovi and Zuari Rivers on the north and River Sal in the South.

FIELD SAMPLING: Field sampling was carried out on 10th June 2006 during the low tide at the three stations namely Polem, Agonda and Benaulim, at the three tides i.e. high tide(HT), mid tide (MT) and low tide (LT), respectively. The preliminary observations revealed the presence of berried crustaceans in the macrofauna, therefore a second set of sampling was done on the 30th of June 2006 mainly to study the fate of egg bearing females and process of benthic recruitment in the area under investigation.

Sampling was carried out for the following parameters:

Macrobenthos:- Samples for macrobenthos were collected using an acrylic core (\emptyset 12cms; Plate 3.2 C). Sediment from surface upto the depth of 10cms was collected and preserved in Rose Bengal – Formalin solution.

In the second sampling, macrobenthic samples were collected using a metallic quadrant (625 cm²; Plate 3.2 D). Sediment from surface to a depth of 5 cms were collected, sieved (Plate 3.2 E) and transferred to plastic packets and preserved in neutralized 5% Formaldehyde.

Sediment was also collected separately for organic carbon (OC), petroleum hydrocarbon (PHC) and textural analysis using an acrylic core of (\emptyset 4.5cms). For sediment chlorophyll, approximately, 1 g of surface sediments was collected from each tidal level (i.e. HT, MT, LT) and stored in icebox under dark condition. Surf water samples were collected from the low tide area for estimating the chlorophyll, dissolved oxygen and nutrients following standard techniques and stored in icebox to prevent biological action (Plate 3.2 F).

Physical parameters like temperature (sediment, air and water) and salinity were recorded using a handheld field Thermometer in (°C) and Salinometer (ORBIT) respectively.

LABORATORY ANALYSIS:

In the laboratory, macrofaunal samples were washed and sieved using a 500-µm sieve under running water and sorted. The fauna was preserved in neutralized 5% Formalin. All the fauna were then identified under stereo zoom microscope (Olympus BX 52) upto the lowest possible taxa level using available keys for the Indian coast. Macrofauna were counted and biomass was estimated by the wet weight method. Population density was converted into no.m⁻² and biomass was expressed as wet weight g.m⁻².

***Emerita* and *Donax* recruitment:** Mole crab *Emerita holthuisi* and Wedge Clam *Donax incarnatus* were the most dominant in terms of faunal abundance therefore population of both the species were separately counted as adult and juvenile. The females carrying eggs were again separated for further analysis. All the eggs were separated counted and studied for any abnormalities.

Sediment organic carbon: - The sediment samples were washed repeatedly to get rid of the salts. Further, they were dried and powdered. The organic carbon was estimated using the Wet oxidation method (El Wakell & Riley, 1957).

Petroleum Hydrocarbons (PHC):- TPH content in sediment was analyzed by a method given by Sleeter et al. (1980).

Chlorophyll (Sediment and Water):- Sediment chlorophyll and phaeophytin was estimated with acetone extraction method (Holm-Hansen, 1978).

Water- 500ml of sampled water was filtered through a GF/F Whatmann filter paper. The chlorophyll was extracted using 10ml of 90% acetone. The reading was taken on the fluorimeter, and the chlorophyll and phaeophytin was estimated by using the formulae.

Sediment- the sediment chlorophyll and phaeophytin was estimated by the same method as above. For this estimate, about 1gm of sediment was taken and the chlorophyll was extracted in 10ml of 90% acetone.

DATA ANALYSIS: -

All raw data were processed using standard MS-EXCEL statistical package. The structure of benthic community at each site was calculated in terms of number of species (S), total abundance, total biomass, Shannon –Wiener species diversity index (H1), evenness (J1) and species richness (SR). Shannon-Wiener species diversity index using \log_2 , Heip's index for evenness and Margalef's index for species richness were calculated according to Pielou (1975) using PRIMER (Plymouth Routines in Multivariate Ecological Research) package (Clarke & Warwick, 1994). The faunal density data was subjected to multidimensional scaling (MDS) ordination and Bray-Curtis cluster analysis. Correlation was sought between the biological parameters (macro faunal density, biomass, diversity) and sediment parameters (OC and PHC).

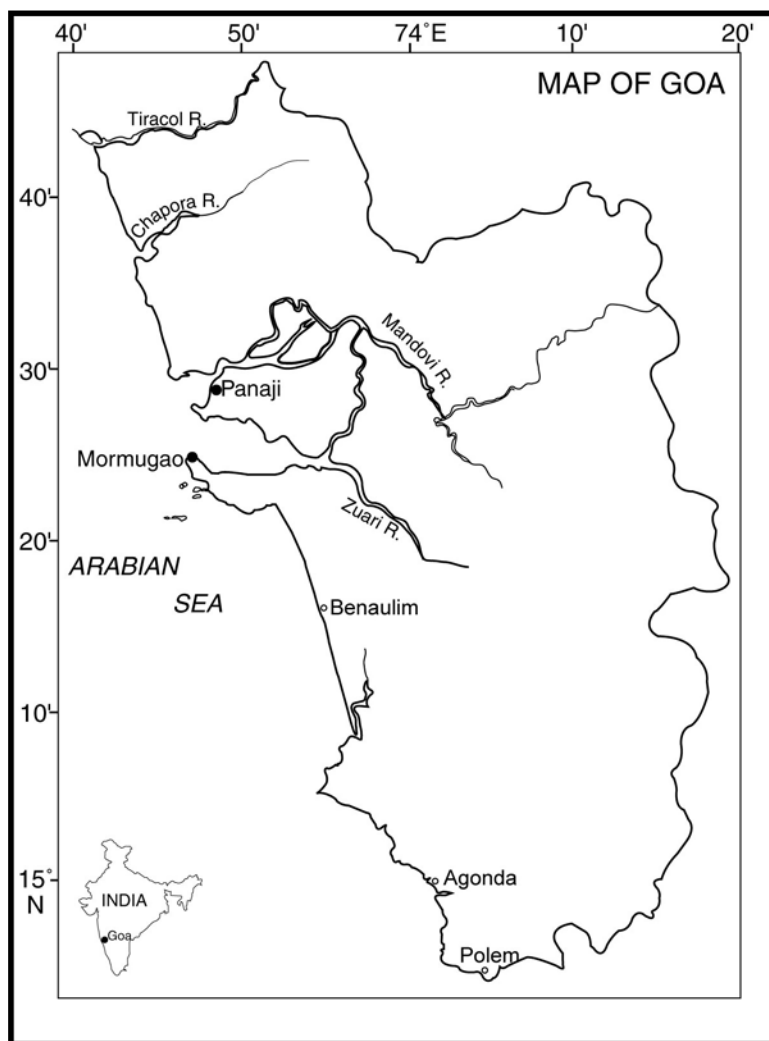


Fig. 3.1: Map showing the Study area

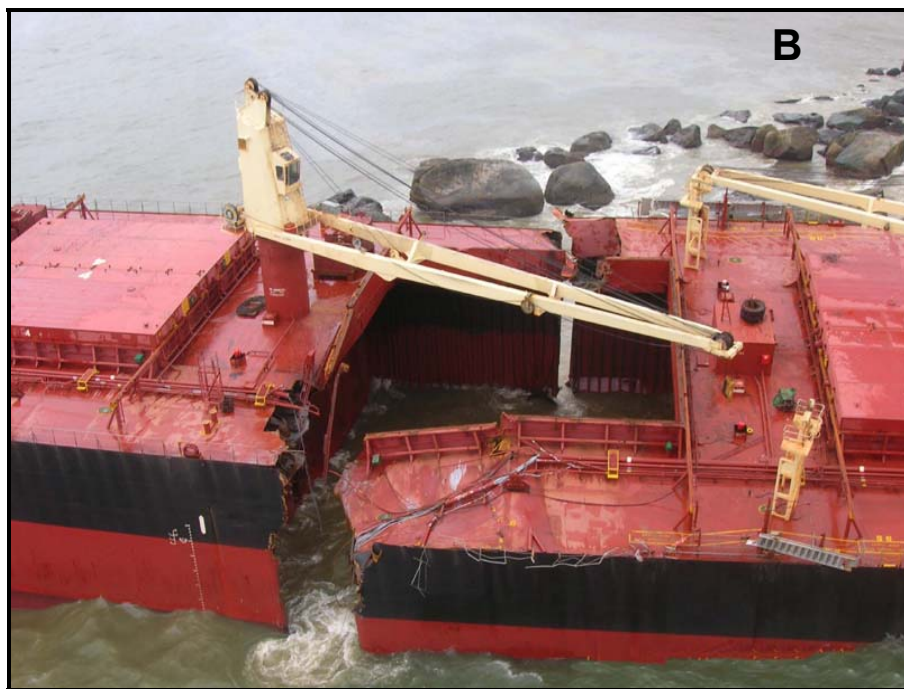


Plate 3.1 A &B: Grounded vessel “MV Ocean Seraya” off Karwar Coast

Source:- (<http://indiancoastguard.nic.in/>)

Plate 3.2



Plate 3.2: Study Area- Agonda (A) and Benaulim (B).



Plate 3.2: Macrofauna sampling - Core (C) and Quadrant (D).



Plate 3.2: Sieving (E) and Sampling (F).

CHAPTER 4

RESULTS

Environmental Parameters

Water characteristics: -

Chlorophyll: - Surf water chlorophyll ranged from 0.11-0.57 $\mu\text{g L}^{-1}$ in the study area with 0.11 $\mu\text{g L}^{-1}$ at Polem and 0.57 $\mu\text{g L}^{-1}$ at Benaulim. Similarly phaeophytin content varied from 0.31-1.93 $\mu\text{g L}^{-1}$, the highest being at Benaulim and the lowest at Polem (Table 4.1).

Salinity: - Sea Surface Salinity (SSS) ranged from 15-30 PSU. A minimum value of 15 PSU was recorded at Polem and maximum at Benaulim (Table 4.1).

Temperature: - Sea Surface Temperature (SST) was 28°C at Polem and 29°C at Agonda. Air temperature at Polem and Agonda was 28°C and 26°C respectively. Sediment temperature was 26°C and 27°C at Polem and Agonda respectively (Table 4.1).

Sediment characteristics: -

Chlorophyll 'a' (Chl-a):- Chlorophyll content varied from 0.01 (Agonda MT) to 0.03 $\mu\text{g. g}^{-1}$ of sediment (Agonda LT) with Polem LT showing 0.014 $\mu\text{g. g}^{-1}$ of sediment. Similarly sediment phaeophytin ranged from 0.03 $\mu\text{g. g}^{-1}$ of sediment in Agonda MT to 0.11 $\mu\text{g. g}^{-1}$ of sediment in Agonda LT, with Polem (LT) showing phaeophytin concentration as 0.05 $\mu\text{g. g}^{-1}$ of sediment. (Table 4.2).

Organic Carbon: Organic carbon varied from 0.46% to 1% in Polem, the values being for HT and LT respectively. In Agonda it was 0.3% in HT, 0.28% in MT and 0.37% at LT. Benaulim showed an organic carbon content of 0.23% in MT and 0.18% in LT (Table 4.2).

Petroleum Hydrocarbons (PHC)- PHC values ranged from 1.96-12.9 $\mu\text{g.g}^{-1}$ of sediment. The highest PHC value of 12.9 $\mu\text{g.g}^{-1}$ was observed at Polem LT (12.9) and lowest (1.97) at Agonda HT (Table 4.2).

Macrofaunal Abundance and Biomass:-

A total of 7 major macrobenthic groups were found in the whole of the study area (Table 4.3). Polem was represented by Nemertenia, Nematoda, Polychaeta and Bivalvia; Polychaeta being the dominant taxa. The macrobenthos of Agonda consisted of Nematoda, Nemertenia, Polychaeta, Bivalvia, Isopoda, Decapoda and Amphipoda. Macrofaunal community of Benaulim consisted of Nemertenia, Polychaeta, Bivalvia, Isopoda and Decapoda.

Macrofaunal community of Polem:

The total abundance at Polem was 1635 no.m^{-2} . The lowest density value was recorded at MT (265 no.m^{-2}) and highest at LT (1083 no.m^{-2}). HT showed an abundance of 287 no.m^{-2} . HT showed only two taxa namely Nemertenia (265 no.m^{-2} ; table 4.4, Fig. 4.1) and Bivalvia (22 no.m^{-2}). MT was dominated by Nemertenia (155 no.m^{-2}), followed by Polychaeta (88 no.m^{-2}) and Nematoda (22 no.m^{-2}). LT was represented by Nemertenia (199 no.m^{-2}) and Polychaeta (884 no.m^{-2} ; Plate 4.2A).the polychaetes here were dominated by *Microphthalmus* sp. (398 no.m^{-2}) followed by *Pisione oerstedii* (331 no.m^{-2} ; Plate 4.2B).

The total macrobenthic biomass at Polem was 0.99 g. m^{-2} . The three tides showed biomass of 0.5 g.m^{-2} (HT), 0.488 g.m^{-2} (LT) and 0.01 g.m^{-2} (MT; Table 4.5 & Fig 4.1).

Macrofaunal community of Agonda:

The total faunal abundance at Agonda was 3513 no.m^{-2} . The abundance was 2607 and 884 no.m^{-2} in MT and LT respectively (Table 4.3). MT was dominated by Nemertenia (1282 no.m^{-2}) followed by Bivalvia (552 no.m^{-2}) while Amphipoda showed the lowest density of 22 no.m^{-2} . LT was dominated by Bivalvia (552 no.m^{-2}) followed by Nemertenia (155 no.m^{-2}). Amphipoda showed the lowest density with 22 no.m^{-2} .The biomass in Agonda ranged from 0.92–8.69 g.m^{-2} recorded at LT and MT respectively

(Table 4.5). At MT crustaceans dominated the macrobenthic biomass (76.6%) 6.66 g.m^{-2} , followed by bivalves (1.72 g.m^{-2}). The biomass of other group was 0.32 g.m^{-2} . LT showed the lowest biomass of 0.94 g.m^{-2} and was dominated by bivalves (0.92 g.m^{-2}).

The abundance at Agonda during the second sampling was represented by Polychaeta, Isopoda (Plate 4.2 D), Decapoda, Mysidaceae and Bivalvia (Table. 4.6; Plate 4.2 E). Agonda MT showed an abundance of 11387 no.m^{-2} dominated by decapods (10885 no.m^{-2}) represented solely by *E. holthuisi*. LT showed an abundance of 120 no.m^{-2} dominated by Decapoda (56 no.m^{-2}) and again by *E. holthuisi*.

Emerita holthuisi : The total density of *E. holthuisi* was estimated a(t) 10885 no.m^{-2} at MT of which 10683 (98%) were juveniles and only 201 (~2%) were adults. At LT the total density was 56 no.m^{-2} of which 40 no.m^{-2} (71%) were adults and 16 (29%) were juveniles (Fig. 4.2).

A single mature female with eggs was collected from the MT (Plate 4.2 F). Fecundity was 1980 eggs and carapace length 18mm. Most of the eggs were in egg stage I(Plate 4.2 A&B) and II(Plate 4.2 D&C) (Vijayaraghavan, 1976).

Donax spiculum: The total density of *D. spiculum* was estimated as 295 no.m^{-2} at MT and all specimens collected were juveniles (100%). At LT the total density was 48 no.m^{-2} and comprised of only juvenile stages (100%).

The biomass in Agonda consisted of polychaetes, isopods, decapods, mysidaceae and bivalves. The biomass at MT was 114.13 g.m^{-2} which was dominated by decapods (100.38 g.m^{-2}); decapods in turn were dominated by juvenile *E. holthuisii* (86.79 g.m^{-2}), followed by adults (13.6 g.m^{-2}). The lowest biomass was accounted due to the presence of isopods (0.008 g.m^{-2}). LT showed a total biomass of 0.07 g.m^{-2} , it was dominated by decapods (0.058 g.m^{-2}) and the lowest was Mysidaceae (0.003 g.m^{-2}).

Macrofaunal community at Benaulim:

The total abundance at Benaulim was 3314 no.m^{-2} . It was 44 no.m^{-2} and 3270 no.m^{-2} for HT and MT, respectively. HT showed low densities of Polychaetes (22 no.m^{-2}) and Isopods (22 no.m^{-2}). MT was dominated by bivalves (2872 no.m^{-2}) and was represented solely by *Donax incarnatus* followed by Decapoda (221 no.m^{-2}) and isopods (22 no.m^{-2})

showing the lowest density. At Benaulim MT bivalves showed the highest biomass (88.4%) 396.4 g.m⁻². Crustaceans showed a biomass of 51.7 g.m⁻² and other taxa showed a biomass of 0.011 g. m⁻².

The macrofaunal abundance in second sampling at Benaulim was represented by Isopoda, Decapoda, Mysidaceae and Bivalvia. The abundance was 6099 no.m⁻² and 1691 no.m⁻² for MT and LT, respectively. MT was dominated by decapods (3288 no.m⁻²) represented by *E. holthuisi* (3283 no.m⁻²) and crabs (05 no.m⁻²); followed by Mysidaceae (2419 no.m⁻²) represented by *Gastrosaccus* sp.

LT was dominated by decapods (1083 no.m⁻²) represented by *E. holthuisi* (1072 no.m⁻²) and *Pinnotheres* sp. (11 no.m⁻²); followed by Mysidaceae (395 no.m⁻²) and the lowest density was of isopods (05 no.m⁻²), represented by *Eurydice*.

Emerita holthuisi: The total density of *E.holthuisi* at Benaulim MT was 3283 no.m⁻² of which 2877no.m⁻² (88%) was juveniles and 405no.m⁻² (12%) were adults. The total density was 1072no.m⁻² of which 730no.m⁻² (68%) was juveniles and 341no.m⁻² (32%) was adults.

The fecundity of *E. holthuisi* (number of eggs/female) ranged from 500 to 2880 no.m⁻² in the specimen measuring 13mm and 17mm respectively.

Donax incarnatus: The total density of *D.incarnatus* at Benaulim MT was 376 of which 307 no.m⁻² (82%) were adults and 69 (18%) were juveniles. At LT the total density was 208 of which 197 (95%) were adults and 11(5%) were juveniles (Fig. 4.3).

At Benaulim, the biomass was 114.11 g.m⁻² at MT and 89.20 g.m⁻² at LT. The MT was dominated by decapods 67.57 g.m⁻² represented by adult *E. holthuisi* (43.65 g. m⁻²), juvenile *E. holthuisi* (19.71 g.m⁻²) and crabs (4.21 g.m⁻²). Biomass was also represented by bivalves (33.02 g.m⁻²). The lowest biomass was shown by isopods (0.006 g.m⁻²). the LT was dominated by decapods (60.68 g.m⁻²) represented by adult(46.17 g.m⁻²), juvenile *E. holthuisi* (5.28 g.m⁻²) and crabs (9.23 g.m⁻²). The lowest biomass was of isopods (0.002 g.m⁻²).

Macrobenthic Diversity in the study area

Highest taxan diversity was observed at Agonda (MT) with 10 taxa. Lowest diversity of 2 taxa was observed both at HT of Polem and Benaulim. Margalef's species richness ranged from 0.17-1.14 (Fig. 4.4). Agonda (MT) and Polem (HT) recorded highest and lowest species richness values. Highest evenness was seen at Benaulim (HT) and Polem (HT) showed lowest evenness values (0.3). Shannon-Weiner diversity was highest at mid tide of Agonda (1.5) and lowest at Polem high tide (0.27)

The cluster diagram shows that the study area was divided into two groups. Stations from Polem (HT, MT, LT) formed one group at 33.46% (Fig 4.5). The second group was formed by the stations from Agonda (MT, LT) showing a similarity of 54%. Stations at Benaulim did not cluster with other stations. Polem HT and MT form one group at 54% similarity. The MDS (Multi-Dimensional Scaling; Fig. 4.6) plot showed clustering of Polem (HT & MT) and Agonda (MT<).

Correlation between the biological parameters and sediment parameters (PHC and Organic carbon) was carried out. PHC showed negative correlation with density (Fig 4.7) and biomass ($r = -0.2$). Species richness and number of species also showed negative correlation with PHC whereas evenness and Shannon-Weiner diversity showed positive correlation. Organic carbon showed a negative correlation with all the biological parameters.

Oil Spills and Fishery

Incidences as well as the quantity of oil spills along the years was compiled to study the effect of oil spills on the fishery production along the West Coast of India, a correlation was plotted between total fish catch (Anon, 2006) and quantity of oil spills from 1985- 2004.(Fig. 4.9).

	Temperature (°C)			Salinity(PSU)	Surf Water (µg/L)	
	Sediment	Water	Air	Water	Chlorophyll	Phaeophytin
Polem	26	28	28	15	0.1137	0.3126
Agonda	27	29	26	29	0.4263	1.2789
Benaulim	--	--	--	30	0.5684	1.9326

		Chlorophyll a (µg.g ⁻¹)	Phaeophytin (µg.g ⁻¹)	OC (%)	OM (mg.g ⁻¹)	PHC (µg.g ⁻¹)
	HT	--	--	0.99	1.76	7.29
Polem	MT	--	--	--	--	5.73
	LT	0.014	0.05	0.46	0.84	12.9
	HT	--	--	0.28	0.50	1.96
Agonda	MT	0.009	0.03	0.28	0.50	3.40
	LT	0.032	0.11	0.37	0.67	2.59
Benaulim	HT	--	--	0.18	0.34	4.53
	MT	--	--	0.23	0.42	4.41

Groups	Polem			Agonda			Benaulim	
	HT	MT	LT	HT	MT	LT	HT	MT
Nematoda	0	22	0	0	221	0	0	0
Nemertenia	265	155	199	0	1282	155	0	44
Polychaeta	0	88	884	0	88	0	22	110
Bivalvia	22	0	0	0	552	552	0	2872
Isopoda	0	0	0	0	398	133	22	22
Decapoda	0	0	0	0	44	0	0	221
Amphipoda	0	0	0	0	22	44	0	0
TOTAL	287	265	1083	0	2607	884	44	3270

	Polem			Agonda			Benaulim	
	HT	MT	LT	HT	MT	LT	HT	MT
Nematode	0	22	0	0	221	0	0	0
Nemertenia	265	155	199	0	1282	155	0	44
Polychaeta								
<i>Glycera alba</i>	0	0	0	0	22	0	0	0
<i>Saccocirrus</i> sp.	0	44	0	0	44	0	22	22
<i>Phyllodoce</i> sp.	0	44	88	0	0	0	0	0
<i>Pisione oerstedii</i>	0	0	331	0	0	0	0	0
<i>Pisionidens indica</i>	0	0	0	0	0	0	0	88
<i>Microphthalmus</i> sp.	0	0	398	0	0	0	0	0
<i>Nerine</i> sp.	0	0	44	0	0	0	0	0
<i>Scoloplos</i> sp.	0	0	22	0	0	0	0	0
Polychaeta 1	0	0	0	0	22	0	0	0
Bivalvia								
<i>Donax incarnatus</i>	0	0	0	0	0	0	0	2872
<i>Donax spiculum</i>	22	0	0	0	552	552	0	0
Isopoda								
<i>Eurydice</i> sp.	0	0	0	0	309	0	22	0
<i>Sphaeroma</i> sp.	0	0	0	0	88	133	0	0
Isopoda 1	0	0	0	0	0	0	0	22
Decapoda								
<i>Emerita</i> sp.	0	0	0	0	44	0	0	221
Amphipoda								
<i>Haustiroidea</i> sp.	0	0	0	0	0	22	0	0
Amphipoda 1					22	22		
TOTAL	287	265	1083	0	2607	884	44	3270

Groups	Polem			Agonda			Benaulim	
	HT	MT	LT	HT	MT	LT	HT	MT
Bivalves	0	0	0	0	1.71	0.92	0	396.4
Crustacea	0	0	0	0	6.66	0.02	0	51.7
Others	0.5	0.01	0.488	0.0	0.3	0.0	0.0	0.0
TOTAL	0.5	0.01	0.488	0.0	8.7	0.9	0.0	448.1

	Agonda		Benaulim	
	MT	LT	MT	LT
Polychaeta	11	0	0	0
Isopoda	41	16	16	5
Decapoda	10885	56	3288	1083
Mysidaceae	155	0	2419	395
Bivalvia	295	48	376	208

	Agonda		Benaulim	
	MT	LT	MT	LT
Polychaeta	1.417	0.000	0.000	0.000
Isopoda	0.008	0.004	0.006	0.002
Decapoda	100.385	0.058	67.573	60.683
Mysidaceae	1.336	0.000	13.520	1.920
Bivalvia	10.986	0.003	33.015	26.598

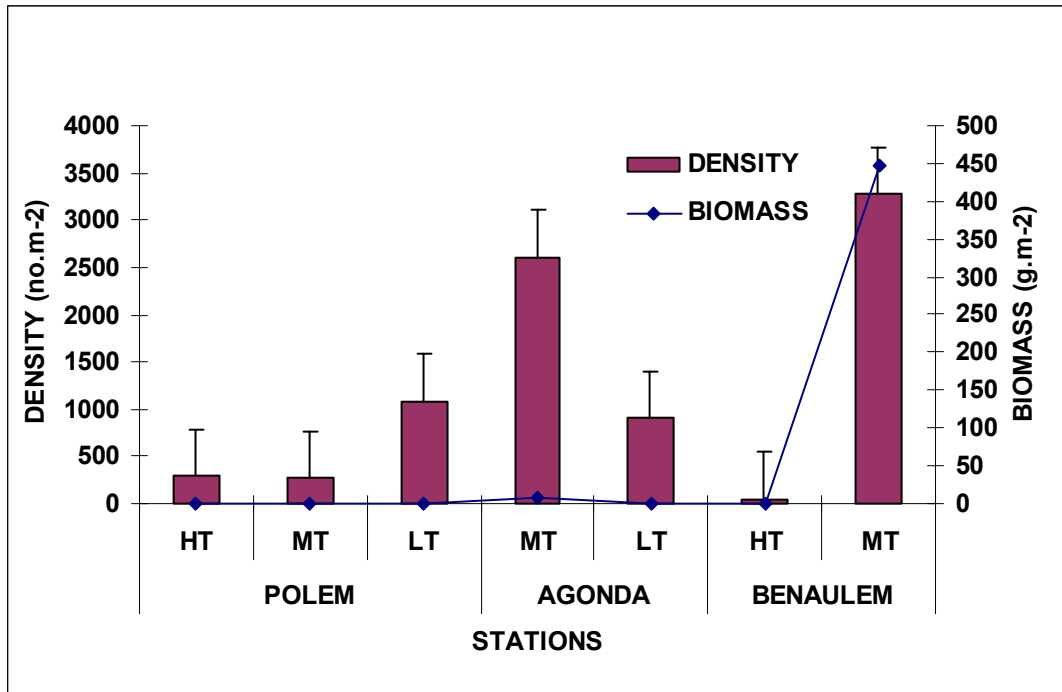


Fig. 4.1: Macrofaunal density (no.m⁻²) and biomass (g. m⁻²) variation in the study area.

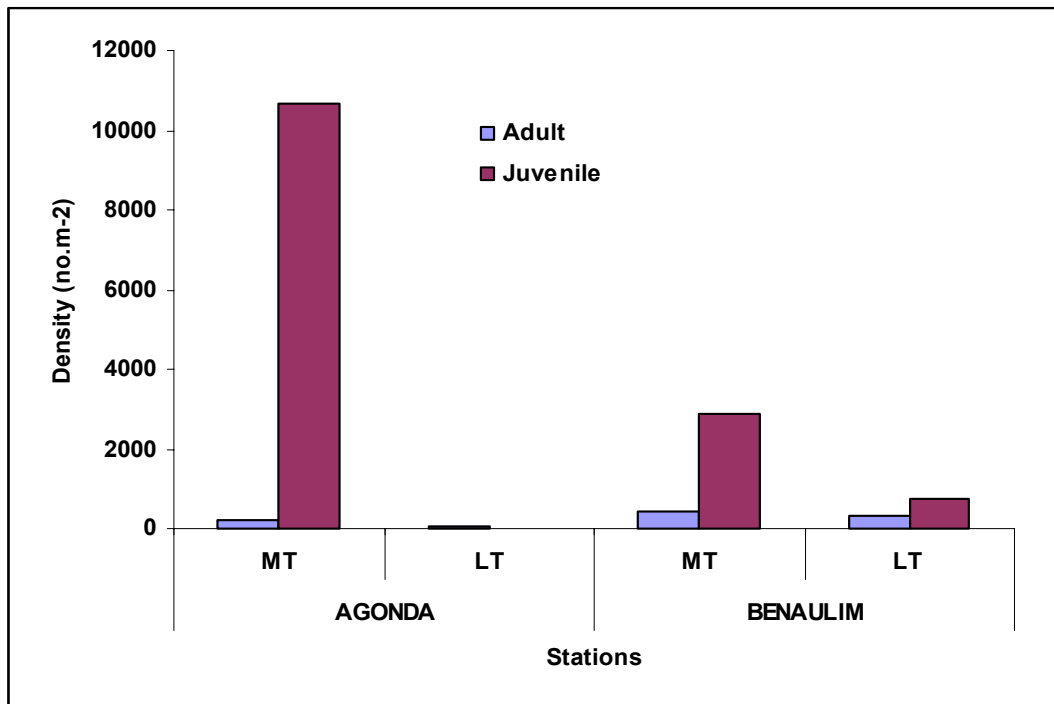


Fig. 4.2: Density of adult and juvenile *E.holthuisi* at Agonda and Benaulim

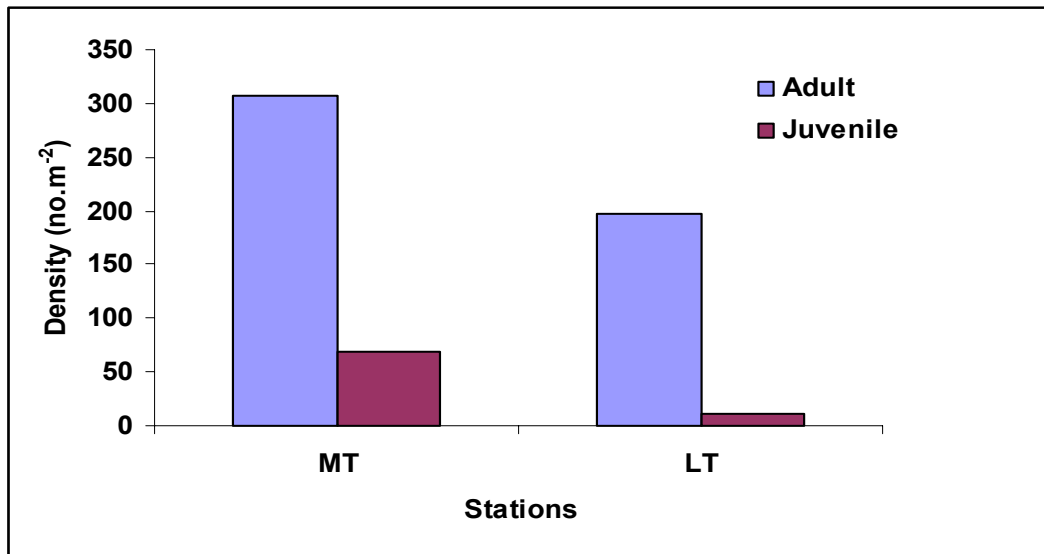


Fig. 4.3: Density of adult and juvenile *D.incarnatus* at Benaulim

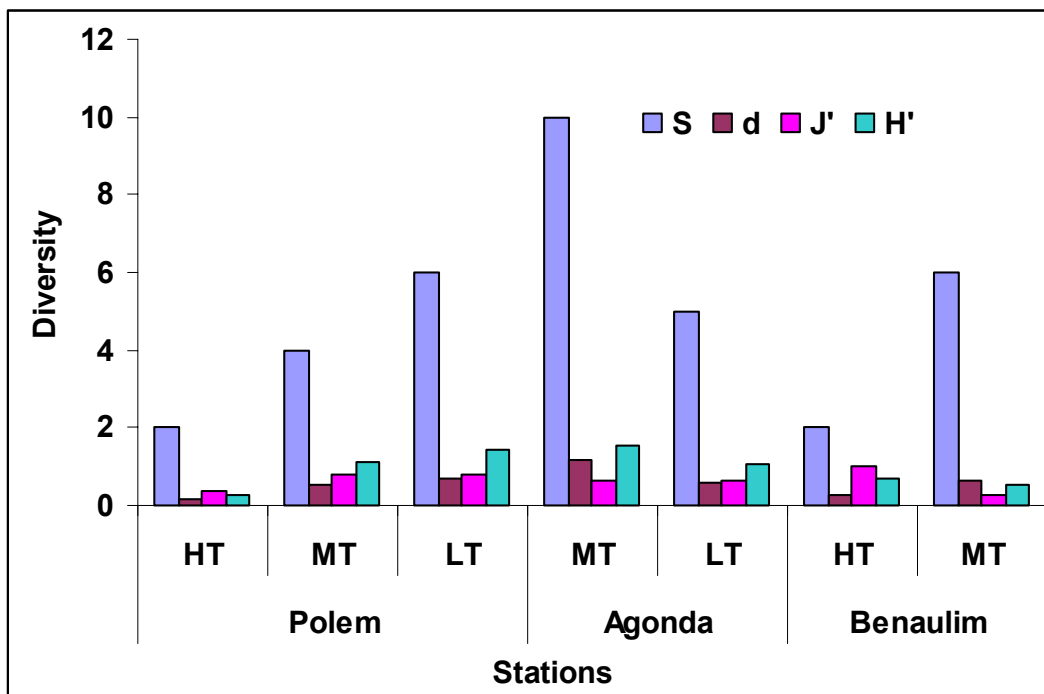


Fig. 4.4: Diversity indices for the study area (S- no. of sp; d-species richness; J'- evenness; H'- diversity)

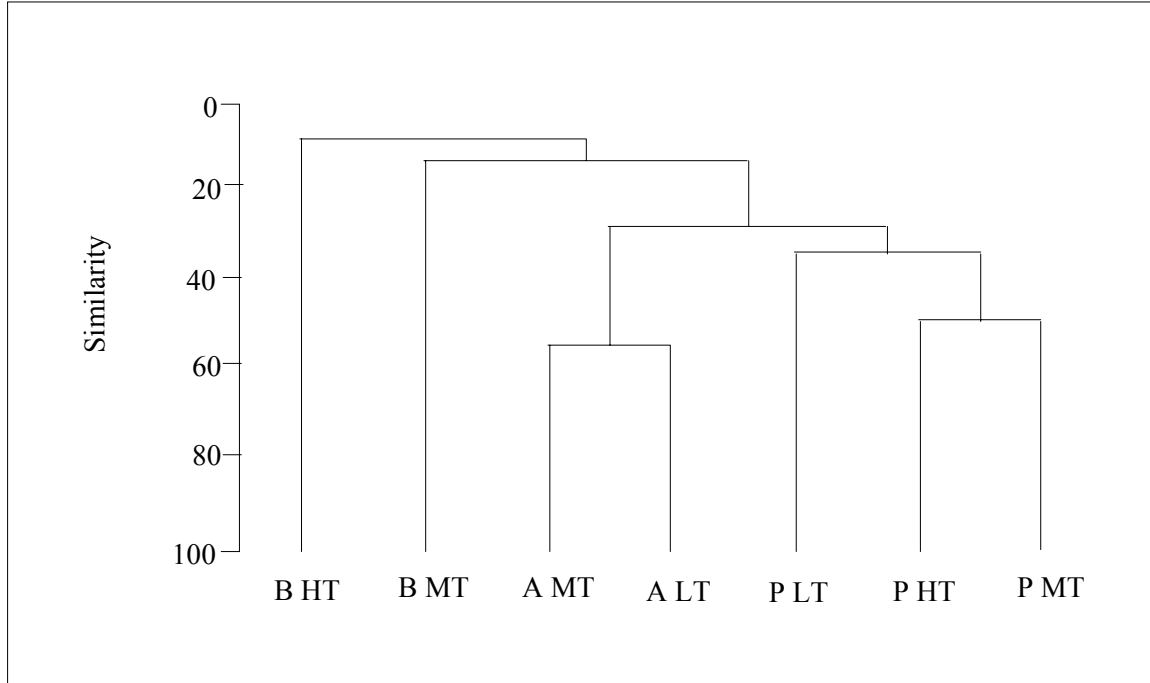


Fig . 4.5: Bray-Curtis cluster based on macrofaunal density.

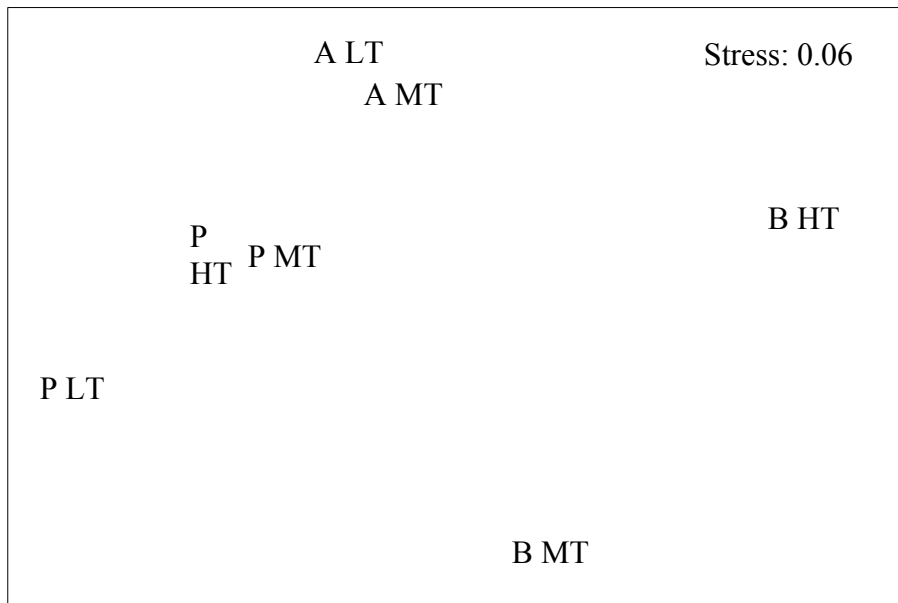


Fig . 4.6: MDS based on macrofaunal density (P- Polem; A-Agonda; B-Benaulim).

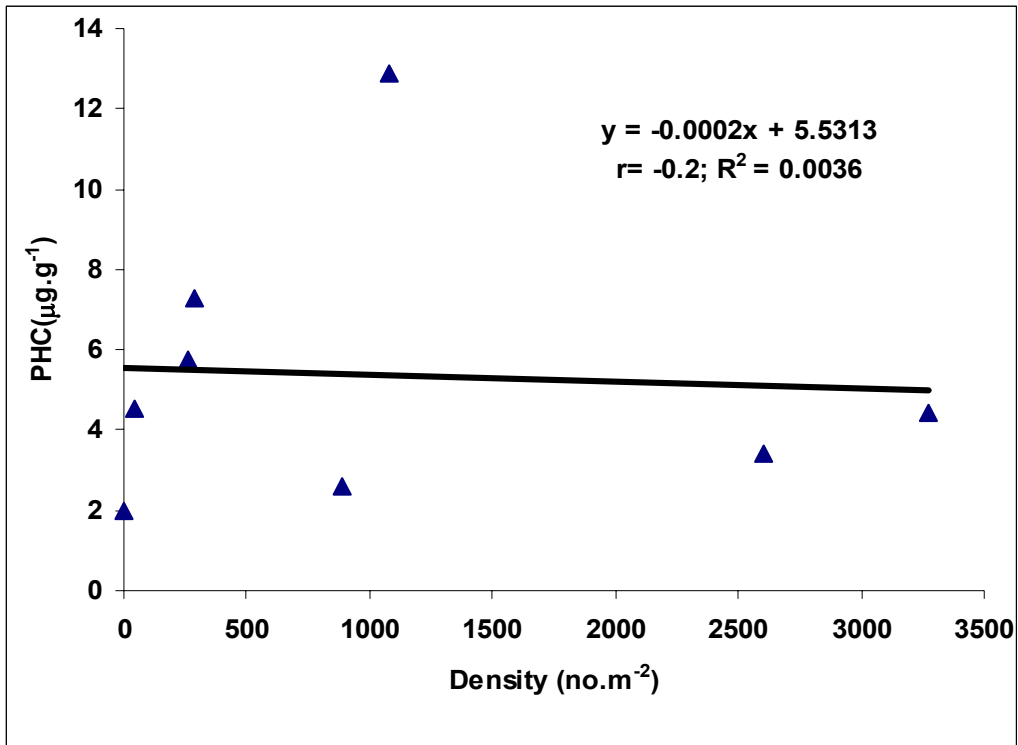


Fig. 4.7: Correlation between macrofaunal density and sediment PHC.

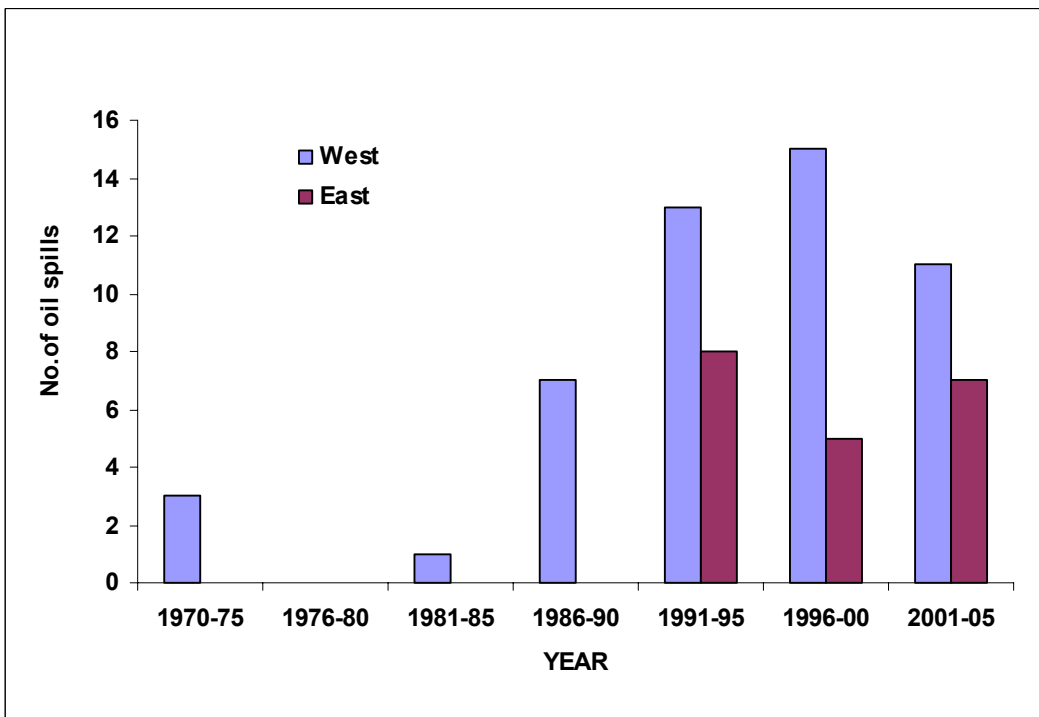


Fig.4.8: Oils spills along the Indian Coast (Indian Coast Guard)

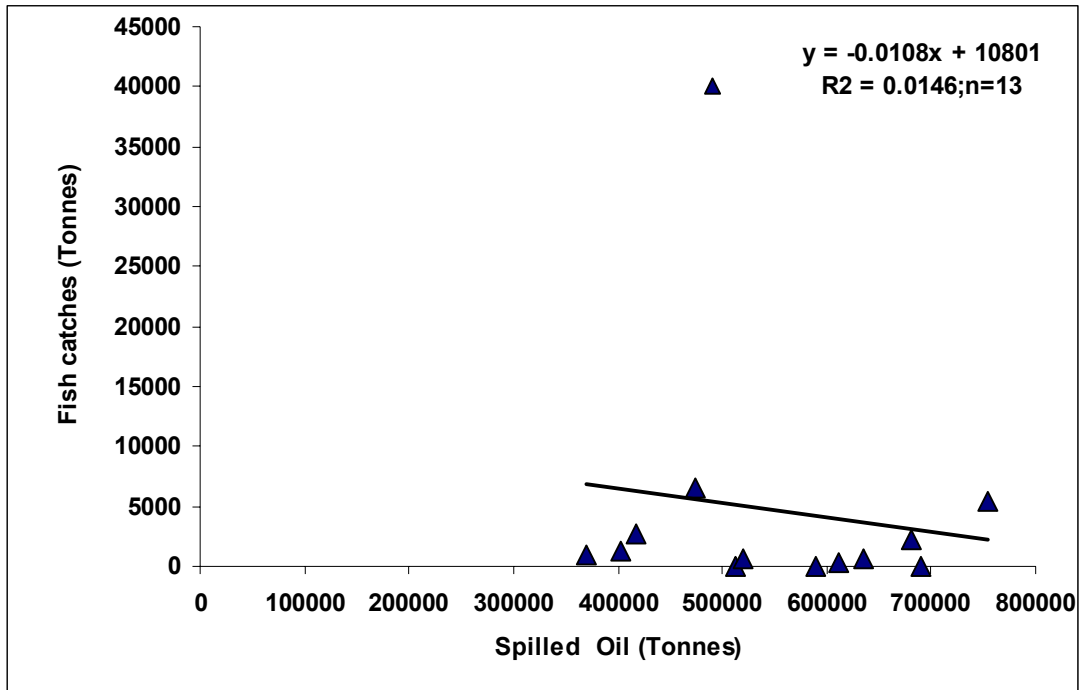


Fig. 4.9: Correlation between pelagic fish catches and quantity of spilled oil from 1985-2004 along the west coast of India.

Plate 4.1

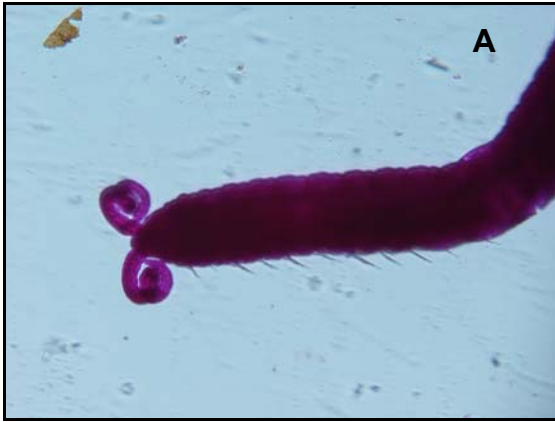


Plate 4.1: Polychaeta – *Saccocirrus* sp. (A) and *Pisione oerstedii* (B)



Plate 4.1: Crustaceans – Amphipoda (C) and *Eurydice* sp. (D)

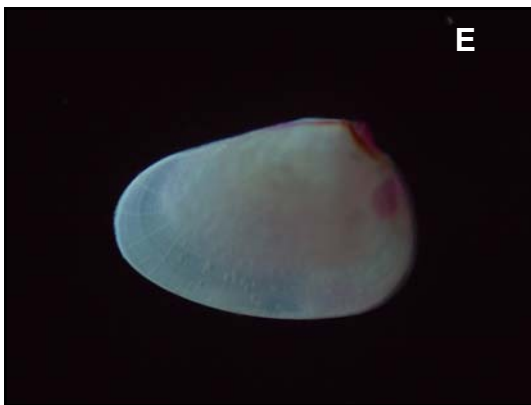


Plate 4.1: Bivalve- *D. incarnatus* (E) and Decapoda- *E. holthuisi* with eggs (F)

Plate 4.2

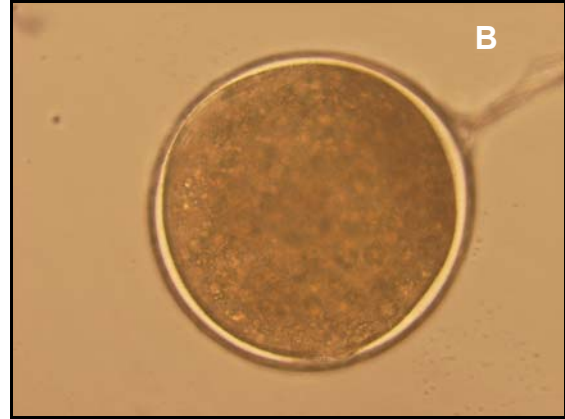
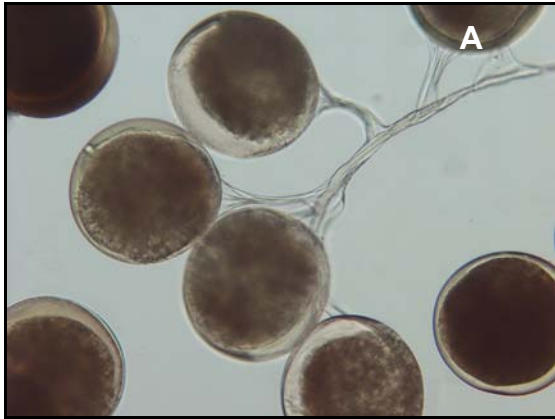


Plate 4.2: Egg stage I of *E. holthuisi* (A & B).

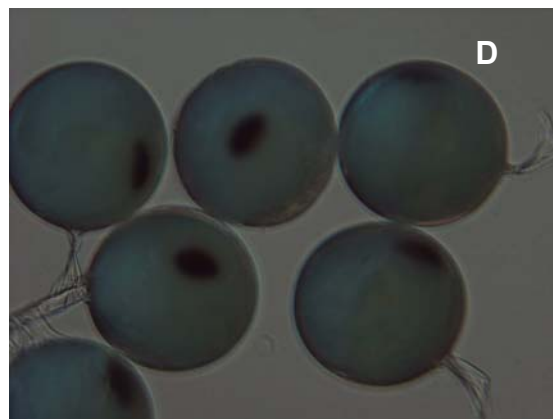
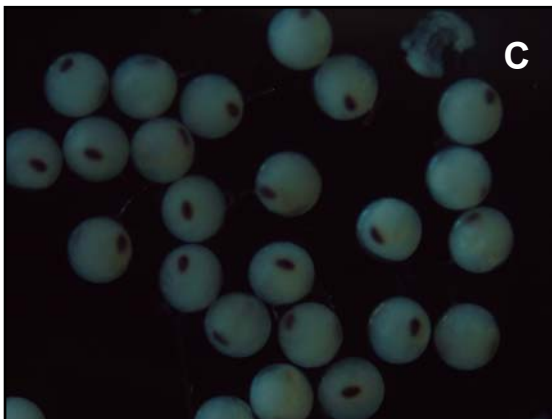


Plate 4.2: Egg stage II of *E. holthuisi* (C&D).

CHAPTER-5

DISCUSSION:

On 30th May 2006 a Panama based bulk carrier “*MV Ocean Seraya*” ran aground off the Oyster rocks near Karwar spilling 650 tonnes of fuel oil into the waters along the Karwar Coast (Plate 5.1A). The spill started spreading towards the Goa coast due to the rough SW monsoon winds. The spill was reported to have affected beaches in south Goa from Polem (Plate 5) to Benaulim. In fact, the frequent occurrence of tar balls and oil pollution is a major threat to tourism, which is the main employment generating industry in Goa. Approximately two million tourists (domestic and foreign) visit Goan beaches every year. Goa, accounts for 12% of all tourist arrival in India. There are around 450 hotels including 11 five star hotels (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 attractiveness of the beaches but it are also known to affect the coastal ecology and fishery on a long-term basis (Ingole et al, 2006). Considering the earlier notion that oil spills affect the intertidal beach ecology (Ansari & Ingole 2002), a detailed investigation was conducted to evaluate the impact of *Ocean Seraya* oil spill on the beach ecology.

The environmental parameters (temperature: air, sediment, surf water; salinity) observed were in accordance to those recorded normally for the monsoon season. Accordingly, the salinity of the surf water ranged from 15-30psu (Table, 4.1). Low salinity at Polem (15psu) was due to heavy rains during the sampling. The values for surf water chlorophyll were highest at Benaulim, whereas the organic carbon was highest (0.1%) at high tide level at Polem.

PHC concentration in the sediment varied from 1.96-13 $\mu\text{g. g}^{-1}$ (Table 4.1; Plate 5.1B). However, the highest PHC value was observed at Polem LT (12.9) and lowest at Agonda HT (1.96). Polem LT showed highest PHC among all the stations, mainly because it is almost at the southern tip of the Goa in close proximity of spill site. Lower values of PHC at other stations could be due to the dilution of PHC, which increases

with distance from the actual spill site. The distribution of petroleum hydrocarbons in surface sediments, particularly in the 0-20cm segment, is of importance to studies of oil contamination, as is understanding of temporal variations in the marine environment. The average sediment hydrocarbon concentration along the Goa coast was estimated to be $7.1\mu\text{g. g}^{-1}$ (Fondekar et al, 1980). This suggests the increase in PHC concentration at Polem (LT). Experimental evidence suggests that about 56% of spilled oil becomes adsorbed onto bottom sediment (Knap & Williams, 1982) where oxidation may take place over several years (Scarratt & Zitko, 1972; Thomas, 1993). Thus, the degree of oil pollution in the marine environment may be more accurately assessed by measuring oil in the sediments (Sen Gupta, et al., 1993) as it persists longer in the sediment. After an oil spill, the oil reacts with smaller particles in the sediment to form oil in water emulsion. These form clay flocs, which, because of their buoyancy, are dispersed and carried away by currents. Also, chemical and biological degradation occur during their transport (Bragg & Yang, 1995). 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).

Biological parameters:

A total of 20 macrobenthic taxa were identified from the intertidal expansion during the present study (Table 4.3 & 4.6). Nemertenia, followed by Polychaeta dominated the faunal abundance at Polem. Polychaete community was dominated by *Macrophthalmus* sp. (45%), followed by *Pisone oerstedii* (37.5%). In Agonda, the crustaceans dominated the intertidal macrofaunal community.

Densities were lower when compared to other tropical beaches, probably due to the ongoing monsoon conditions; as macrobenthic communities are known to respond negatively to monsoonal rains. Since severe beach erosion takes place at various locations during the monsoon, and only species capable of migrating persist (Alongi, 1990). On a sandy beach at Calangute, Goa, erosion and accretion processes displace and bury infauna in the more inclined, high intertidal sands. Other studies also have

shown devastating effects of prolonged torrential rains on the intertidal fauna in Goa (Achuthankutty, 1976; Harkantra & Parulekar, 1985; Ingole & Parulekar, 1998). According to Nair (1978) change in sediment texture during monsoon has a direct bearing on the distribution of certain faunal groups, especially polychaetes and gastropods that recover with return of stable conditions.

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). Spawning is triggered by fall in salinity, which is responsible for increased reproductive output of species with planktonic larval stage, such as bivalves (Broom, 1982). Another faunal response to low salinity during monsoon is mortality (Goodbody, 1961).

Emerita holthuisi, a widely distributed sand crab, was dominant in terms of density and biomass. Juveniles dominated the *E. holthuisi* population and contributed to >80% of the total macrofaunal abundance. The major spawning season of *E. holthuisi* extends from December to June with a peak in March and supplementary minor peak in October (Achuthankutty & Wafar, 1976). As a result, individuals are being recruited almost throughout the year. However, the main recruitment period is June-July. Having recruited to beach population at ~3mm carapace length, individuals take about 9 months to grow to adult size. This almost agrees with the observations of Ansell et al (1972) on south-west Indian beaches, where they grow to the adult size of 12 mm in 8 or 9 months.

In Benaulim beach, the bivalve *Donax incarnatus* showed higher biomass as well as density. *D. incarnatus* is known to dominate the intertidal beach of Benaulim (Nair, 1978). Mysid, *Gastrosaccus* sp. also occurred in high density (2418.7 no.m⁻²), which agrees, to the study of Nair (1978) who reported swarm of *Gastrosaccus* sp. during monsoon.

Clustering and MDS plot showed that, all the three study areas differ in macrofaunal community (Fig. 4.5 & Fig. 4.6). Benaulim stations (HT & MT) did not cluster with other

sites, since the mid tide level was dominated by *D. incarnatus* (2872no.m⁻²) and high tide was represented by very low density of the polychaete, *Saccocirrus* sp. (22 no.m⁻²) and the Isopod, *Eurydice* sp. (22 no.m⁻²). In Polem HT (265 no.m⁻²) and MT (155 no.m⁻²) was dominated by Nemertenia and showed 48% similarity whereas; LT was dominated by polychaetes (884 no.m⁻²). Similarly, Agonda (MT and LT) clustered at 54% due to the presence of the bivalves, *D. spiculum* in similar density (552 no.m⁻²).

Correlation between PHC and macrofaunal density showed a negative but not a significant relation (Table 4.7 & Fig. 4.8). Though the present study did not show direct impact of oil spill from “*MV Ocean Seraya*” on the intertidal macrobenthic community, even though the PHC values were high (13µg. g⁻¹) at Polem low tide. Further, sediment-associated oil from major spills have shown to persist in the marine environment for many years, and can be re-released in potentially toxic concentrations (Seip, 1984; Vandermeulen et al. 1978). The 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 the crustaceans (Dauvin, 1998). Benthic amphipods are exceedingly sensitive to oil pollution (Sanders et al., 1980). 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 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 (2006) demonstrated that relatively small scale but persistent oil spill not only reduced benthic standing stock (abundance and biomass) but also eliminated some of the oil sensitive species from the intertidal habitat.

The vulnerability of organisms to oil will tend to be related to seasonal changes in their distribution and abundance. Accordingly, for a particular species, spilled oil may have

less impact at one part of the year than another. Monsoon is the recruitment period of most tropical benthic organisms and commercial fish. It is evident from the present study that major recruitment of *Emerita* spp. occurs during the monsoon as the population was entirely dominated by juveniles (> 80%). More than 90% of the benthic organisms have a planktonic larval stage (Thorson, 1957). Generally, the effect of oil spills is first observed in pelagic organism, if it occurs in open waters. However, an oil spill is not stationary in the water column, it spreads over larger surface area under the influence of winds (monsoonal or otherwise), during which, it affects the pelagic organisms to a large extent.

There is an increasing amount of data on the susceptibility of early developmental stages to oil, especially at the cellular and sub-cellular level, sometimes at concentrations substantially lower than those inducing morphological changes in juvenile marine organisms (Malins 1982). In an experiment conducted on the cod embryo Kuhnhold (1974) concluded that embryos were most sensitive during the first few hours of development. The cumulative impact of *North Cape* oil on winter flounder embryos was an estimated 51% reduction in the number of embryos surviving to the larval stage (Hughes, 1999). Napthalenes and phenanthrenes, both light weight PAHs, are among the most toxic fractions of oil to marine fish (Gundersen et al., 1996). When No.2 oil is exposed to sunlight, more persistent and toxic compounds are produced (Larson, et al, 1977) and the peroxides formed react with DNA to produce mutation. Many commercial fishes exploit the estuarine area for spawning and development of sensitive embryonic and larval stages. This could work against these species when the estuaries become contaminated with toxic material such as oils. Survival through planktonic development stages is believed to be the most important event controlling abundances of marine organism. Also the early stages of these species are vulnerable to significant losses due to natural events and anthropogenic disturbances like oil spills (Hughes, 1999).

Benthos is the major food source for demersal fisheries and benthic production shows strong seasonality; consequently any impact on benthos will eventually 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). Near shore region and west coast shelf region of India showed high demersal fish catch largely due to the upwelling phenomenon (Warren, 1992).

The marine fish landing for the year 2004 was 635094 tonnes along the west coast (Anon, 2006). Fish catch has increased in the last decade which is attributed to mechanization and phenomenal increase in the number of fishing trawlers as well as advancement in gear technology (Ansari et al., 2006). On the other hand, landings of major fisheries resources in the Indian Ocean region have declined significantly and overexploitation is considered as a major problem the world over. Thus, overexploitation and increased incidents of oil spills along the west coast probably have further effect on the fishery production of the area.

The west coast accounts for 73% of the total marine fish landing in the country. It has been observed that there is an increase in the incidents of oil spill in the Arabian Sea, with majority of them occurring during the monsoon season. This could certainly affect marine organisms including pelagic fishery. The environmental condition during SW monsoon period along the west coast is optimum with plenty of plankton food resulting from the seasonal upwelling. Spawning periodicity of majority of fishes coincide with monsoon, so that their larvae could utilize the abundance phyto- and zooplankton population for survival (Goswami, 1998).

Hydrocarbons can greatly reduce the individual organism's chances for survival (Rosenthal & Alderdice 1976) and accordingly population changes are of potential concern. Significant changes in commercial stocks do take place in inshore areas, although attempts are not usually made to link them with any single pollutant (McIntyre, 1982) however, oil spills could be one of the major reasons for fluctuation in total fish catch. McIntyre (1982) comments upon the absence of long-term adverse effects on fish stocks that can be attributable to oil, but is cautious to note that local impacts can be extremely damaging in the short-term. Hence, the fish production from specific localities can be tainted from exposure at the parts per billion (ppb) level, and remain unmarketable for long periods. 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. Data presented in (Table 5.1) shows

increase in incidences of oil spills during the monsoon season, due to the rough weather. Model studies, based on historical data of winds and surface currents indicate that the Indian west coast is vulnerably exposed to any spills in the Arabian Sea, only during the SW monsoon months May-September when the along shores surf currents develops an easterly shoreward component (Gouviea & Kurup, 1977; Kurup 1983).

Vulnerability of the Indian Coastline to Oil Spill:

On an average, 40 super tankers pass through Indian coastal waters daily. In addition, Indian ports and harbours handle about 3810 tankers carrying about 84 million tonnes of petroleum/oil/lubricants every year (<http://www.cpcb.nic.in/highair6.htm>). Almost 45% of the world's oil transport originates from Middle East countries and 70% of the total oil tanker movement passes through Indian Ocean (Fig.1.1). Indian peninsular region lies between the two major oil choke points of the world, the **strait of Hormuz** on the West and **strait of Malacca** on the east coast (Fig.1.1). Due to the narrowness of these lanes, the routes are accident-prone. According to (Anon, 2003) an accident even to one of the very large crude carriers could spill up to 100,000 tonnes of oil on the Indian coastline. It is undoubtedly clear from the above data that Indian coast, particularly the west coast, is located at a vulnerable position to the oil pollution.

Moreover, commercial shipping activities along the Indian coast have also increased immensely in recent years. The total vessel traffic as of 2003-04 of the 13 major ports on the Indian coast was 16857 (www.ipa.nic.in), which includes dry bulk, liquid bulk, break bulk and containers. Handling losses at oil terminals in the east and west coast of India in the recent years, also show phenomenal increase. Thus, the Indian coastline is under a persistent threat.

Data presented in figure 5.1, suggest that even though there has been an increase in volume of oil movement, the number and volumes of tanker spills have substantially decreased since the 1970s globally. Contrary to the global scenario, incidents of oil spills along the Indian coast have increased with $\approx 71\%$ of the incidents occurring along the west

coast (Table 5.1). Also majority of the oil spills occurred during the SW monsoon. The west coast in particular is more prone to oil pollution due to the petroleum traffic in the Arabian Sea. Monitoring of different components of oil pollution in the Arabian Sea has been in progress since 1978 and a good database has been built up (Sen Gupta *et al.*, 1990). This data indicate a frequency of 65% positive sightings for oil slicks, mean concentrations of 0.59 mg m⁻² (range from 0-6 mg m⁻²) of floating tar, average 7.1 µg.l⁻¹ of dissolved/dispersed hydrocarbons (range 0 - 41.6) in the upper 20 m and an annual average of 20-28 g m⁻² of beach tar (Dhargalkar *et al.*, 1977).

Increase in incidence as well as quantity of oil spills, at the present rate, along the West coast of India will have long-term effect on intertidal as well as subtidal communities.

Vulnerability of Goa coast to oil spills

Like other states along the west coast of India, Goa lies along the oil tanker route and every year millions of tonnes of oil and its products are transported along this route. As indicated in Table 5.2, four oil spills occurred along the Goa coast since 1994, and interestingly all the incidences occurred during the SW monsoon. The ore carrier “*MV Sea Transporter*” carrying 1000 tonnes of fuel oil grounded a few meters from Sinkerim beach in June 1994. Short- and long-term effects of a fuel oil spill on meiofauna were investigated by Ansari & Ingole (2002). A significant reduction in the absolute abundance of meiofauna was observed immediately after spillage, particularly at Sinkerim beach, the site of spillage. Long-term response showed no apparent oil induced changes at major taxa levels. The ecotoxicological effects of oil spill from the grounded ore carrier “*MV River Princess*” on the intertidal benthic organism of Sinkerim-Candolim was investigated by (Ingole et al, 2006). The vessel carrying approximately 65 tonnes of oil ran aground in June 2000 along the Sinkerim-Candolim-Calangute beach. The result of the study suggests that the vessel not only affected the benthic community and beach morphology but also may have long-term impact on the local fishery. PHC concentration at the grounded site (Candolim) was high. As seen in (Fig. 5.2) the hydrocarbon showed further increase from 43 to 58 µg.g⁻¹ (Ingole, 2006 unpublished data). Increase in values of hydrocarbon could be due to

the possible leakage from the grounded vessel and their accumulation in the sediment (Ingole et al, 2006). Further hydrocarbon values were highest at 6-8 cm depth (Fig. 5.3). The macrobenthic community of Candolim showed decrease in species from 27 (Harkantra, 1984) to 11 species (Ingole et al., 2006). On 23 March 2005 an iron-ore barge Prapti collided with a Singaporean bulk carrier *MV Maritime Wisdom*, anchored about 4 nautical miles off Aguada, rupturing the carrier's oil tank and spilling about 110 tonnes of Heavy Fuel Oil in the sea (Fondekar, 2005).

Mormugao is one of the important port along the west coast. It accounts for about 50% of the 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 in 1963. 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 2002-2003 the port handled 7.5% of the total traffic handled by all the eleven major ports of India (<http://www.mormugaoport.gov.in/>). 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 bestowed upon Goa, the role of Mormugao port will be enhanced even further in the years to come. As a result, the Goa Coast has become more prone to increased oil pollution.

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.

Fate of Spilled oil (Fig. 5.4): Almost 60% of the oil consumed in the world is transported by tankers and accidental oil spills account for 15% of the annual total amount of oil entering the sea (NRC, 1985). The form and behaviour of oil spilled at sea are contingent

upon its composition, as well as various biotic and abiotic factors. The oil spreads quickly over the surface, often covering extensive areas. Oil slicks travel downwind at 3 to 4% of the wind speed, spreading at a rate dependent on the water temperature and composition of the oil. Light oil spreads faster than heavy oils (Clark, 1992). Several physical-chemical processes evaporation, photochemical oxidation, emulsifications, and dissolutions initiate changes in the composition of oil on the sea surface within hours of a spill. Evaporation effects are greatest for light crude oil and refine products to 75% of the spilled oil compared to heavy oil where only 10% of the oil evaporates (Kennish, 1997). Oil-in water emulsion form by wave and currents mix the oil and sea water. The formation of water-in-oil emulsion (“chocolate mousse”) can exacerbate the impact of polluting oil. This emulsion enables the oil to persist for months at sea, where it can be transported many kilometers from the spill site, endangering sensitive habitats. Tar balls measuring 1mm to 25cm in diameter comprise the heaviest residues of crude oil. Tar being heavier falls to the bottom causing further damage to benthic organism and their supporting food webs, especially the demersal fishes. Tar balls and mousse formation degrade extremely slowly in marine waters. Tar balls deposited in shallow areas and the slicks deposited at the bottom are stirred up by the wave action particularly during the monsoon and are washed ashore frequently. Periodic tarball and raw oil pollution are observed on all major beaches, around 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 known (Sen Gupta et al, 2002). 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 year data, gave a figure of 40 tonnes of yearly deposit of tar balls along the beaches of Goa (Sen Gupta et al, 2002)(Plate. 5.1B). In August 2005 an oil spill from an unknown source caused tar ball deposition along the major tourist beaches and heavy mortality of beach communities. (www.nio.org).

Conclusion

Benthos is an important component of the marine ecosystem. It is a major food source for higher organisms, especially the demersal fishes. The west coast of India is very diverse and contributes to > 70% to the marine capture fishery of the country. Increase in incidents of oil spills along the Indian coast, in particular the west coast in last 10 years will have a negative impact on the coastal ecosystem. Benthos are considered as a useful tool to evaluate the ecological quality of the marine ecosystem. Our study certainly provides essential data on the status of sediment PHC and benthic community of the three intertidal beaches of Goa. Efforts are therefore required to reduce incidents of oil spills, particularly in ecologically sensitive areas, thereby reducing overall ecological and socio-economic impacts.

Although the study was based on short-term sampling, it did show marginal increase in the sediment PHC. The impact of the oil spill from “*MV Ocean Seraya*” on the intertidal macrofauna was visible but not very significant. The increasing trend of oil spills around the Goa coast (four oil spills in the last five years) could certainly have a negative impact on the marine community, as observed earlier (Ingole et al., 2006,) and the economy in terms of fishery and tourism. A comprehensive long-term investigation is therefore required to evaluate the impact of oil pollution on coastal ecology that will help in conserving the coastal biodiversity.

Table 5.1: Major oil spills on Indian coast since 1970*			
Date	Qty. Spilled (T)	Position	Vessel
1970			
Aug 4	15,622 / furnace oil	NW coast of India(off Kutch)	Greek oil tanker 'Ampuria' .
1973			
Jun 18	18,000 / LDO	NW coast of India of Arabian Sea	MT Cosmos Pioneer
1974			
Sep 26	3,325 / furnace oil	Kiltan , Lakshadweep.	American Oil Tanker 'Transhuron'
1982			
	NK	West Coast	Sagar Vikas
1988			
Oct 24	1000	Bombay Harbour, Maharashtra	Lajpat Rai
1989			
	NK	West Coast	SEDCO 252
Jun	5500	795 NM SW of Mumbai	MT Puppy
Aug 4	NK	Bombay Harbour,	ONGC Tanker
Aug 29	NK	Saurashtra Coast, Gujarat	Merchant Ship
Aug 29	NK	Bombay Harbour,	NK
1990			
Mar 22	NK	NW of Kochi, Kerala	Merchant Ship
1991			
Sep 7	692/FO	Gulf of Mannar, Tamil Nadu	MT Jayabola
Nov 14	40000/Crude	Bombay High, Maharashtra	MT Zakir Hussain
1992			
Feb 22	Tanker Wash	40 NM S of New Moore Island, Bay of Bengal	Unknown
Apr 2	1000/Crude	54 NM West of Kochi, Kerala	MT Homi Bhabha
Aug 16	1060/SKO	Madras Harbour, Tamil Nadu	MT Albert Ekka
Nov 17	300/FO	Bombay Harbour, Maharashtra	MV Moon River
1993			
Jan 21	40000	Off Nicobar	Maersk Navigator
Mar 28	NK/Crude	Off Narsapur, Andhra Pradesh	ONGC rig, Kumarada
Apr 29	110/Crude	Bombay Harbour, Maharashtra	MT Nand Shivchand
May 10	90/FO	Bhavnagar, Gujarat	MV Celelia
May 17 BHN	6000/Crude	Bombay High, Maharashtra	Riser pipe rupture
Aug 2	260/FO	Off New/Mangalore	MV Challenge

Date	Qty. Spilled (T)	Position	Vessel
1993			
Oct 1	90/Crude	Cochin Harbour, Kerala	MT Nand Shivchand
1994			
May 12	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 20	100/FO	Bombay Harbour, Maharashtra	MV Maharshi Dayananad
Nov 27	288/HO	Off Madras, Tamil Nadu	MV Sagar
1995			
Mar 26	200/Diesel	Off Vizag, Andhra Pradesh	Dredger Mandovi - 2
Sep 24	-/FO	Off Dwarka, Gujarat	MC Pearl
Nov 13	Tanker Wash	Eliot beach, Chennai.	Unknown
1996			
May 21	370 FO	Off Hooghly River.	MV Prem Tista
Jun 16	120/FO	Off Prongs Lighthouse, Maharashtra	MV Tupi Buzios
Jun 18	132/FO	Off Bandra, Maharashtra	MV Zhen Don
Jun 18	128/FO	Off Karanja, Maharashtra	MV Indian Prosperity
Jun 23	110/ FO	Off Worli, Maharashtra	MV Romanska
Aug 16	124/FO	Malabar Coast, Kerala	MV Al-Hadi
1997			
Jan 25	Tank Wash	Kakinada Coast. AP	Unknown
Jun 19	210/FO	Off Prongs Lighthouse, Maharashtra	MV Arcadia Pride
Jun 19	NK	Hooghly River, West Bengal	MV Green Opal
Sep 14	Naptha, Diesel Petrol	Vizag, Andhra Pradesh	HPC Refinery
Aug 2	70/FO	Off Mumbai, Maharashtra	MV Sea Empress
1998			
Mar 10	Gas Leak	Bombay High, Maharashtra	Drill Rig Noble
May 12	Gas Leak	Bombay High, Maharashtra	Bombay High Platform
Jun 1	20/Crude	Off Vadinar, Gujarat	Vadinar, SBM
Jun 9		Off Porbandar, Gujarat	Ocean Barge

Date	Qty. Spilled (T)	Position	Vessel
Jun 9		Off Veraval, Gujarat	Ocean Pacific
Jul 8	15/FO	Mul Dwarka, Gujarat	Pacific Acadian
2000			
Jul 19	-	Off Sagar Island, West Bengal	MV Prime Value
Sep 8	-	Off Fort Aguada, Goa	MV River Princess
Dec 17	1/FO	Bombay Harbour, Maharashtra	MV Stonewall Jackson
2001			
Jun 8	-	Vadinar, Gulf Of Kachchh,	Not Known
Jul 10		Hooghly River, West Bengal	MV Lucnam
Aug 14		SBM Vadinar, Gujarat	
2002			
Sep 23		220 NM Off Pt Calimare	MV Hiderbahy
2003			
Apr 29	1.8T/ light crude oil	05 miles Off Kochi, Kerala	MT BR Ambedkar
May 9	2000/Naptha	Mumbai Harbour	MT UPCO_ III
May 18	4 NM Oil	Off Haldia, West Bengal	MV SEGITEGA BIRU
Aug 10	300/Crude Oil	ONGC Rig (BHN), Maharashtra	URAN Pipe Line
2004			
Feb 28	01/Crude Oil	ONGC Pipe line at MPT Oil Jetty	Crude Oil Transfer.
Oct 1	0.56T	Berthed - MPT – 8, Goa	
2005			
Mar 23	110 Metric Ton	Off Aguada Lighthouse, Goa	MV Maritime Wisdom
Jun 30	49,537/Cargo & 640/FO	Vishakhapatnam Port	MV Jinan VRWD - 5
Jul 4	350 cu m Base Lube Oil	Mumbai Harbour	Dumb Barge Rajgiri
Jul 25	33 Ton FO	NE of Paget Island (N. Andaman)	MV Edna Maria
Jul 27	80 Ton	Of Prongs Lighthouse, Off Mumbai	OSV Samudra Suraksha
Aug 31	-	9 NM Off Tuticorin	MV IIDA
Sep 20	100 Ton	Off Vishakhapatnam	MV Royal Ocean 2
2006			
May 31	650 /FO	Oyster rocks, Karwar	MV Ocean Seraya

Abbreviations: FO: Fuel Oil; HO: Heavy Oil; (*Source: Coast Guard Headquarters, Delhi).

Table 5.2: Oil Spills in Goa.					
Sr.no.	Ship name	Date & Year	Location	Oil lost & type (tonnes)	Effect
1	MV Sea Transporter	Jun 5 1994	Grounded at Siquerim	1025/crude oil	Meiofauna
2	MV River Princess	Jun 6 2000	Grounded at Candolim	-	Benthic fauna
3		Oct 2004	Berthed - MPT - 8, Goa	0.56	
4	MV Maritime Wisdom	Mar 23, 2005	4.2 NM Off Aguada Lighthouse, Goa	110 Metric Ton	

Source: Coast Guard Headquarters, Delhi.

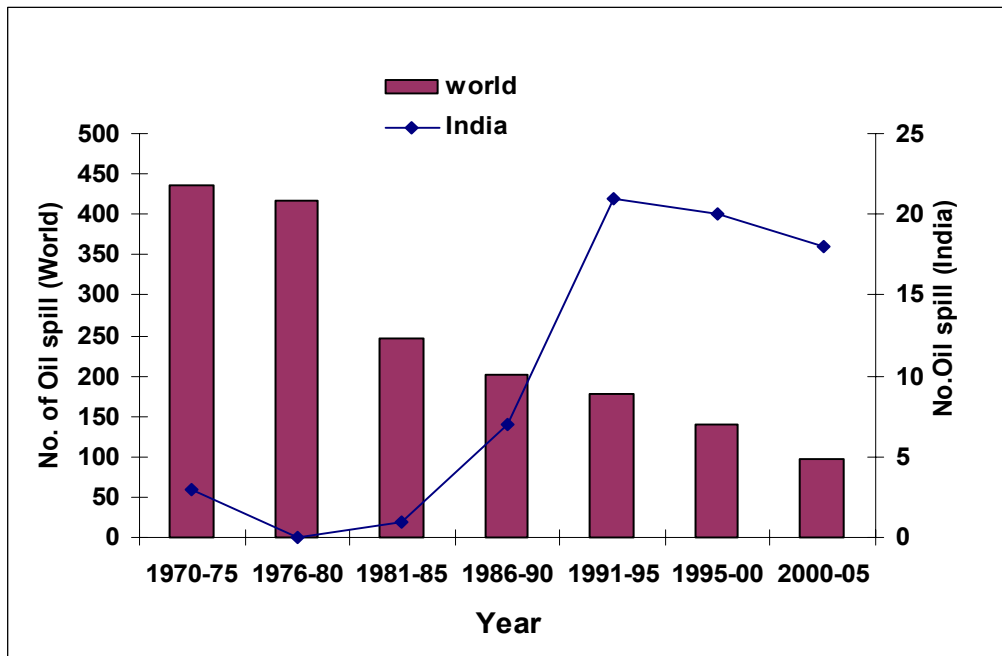


Fig. 5.1: Comparison of number of Oil spills (India and World) Source:ITOPF)

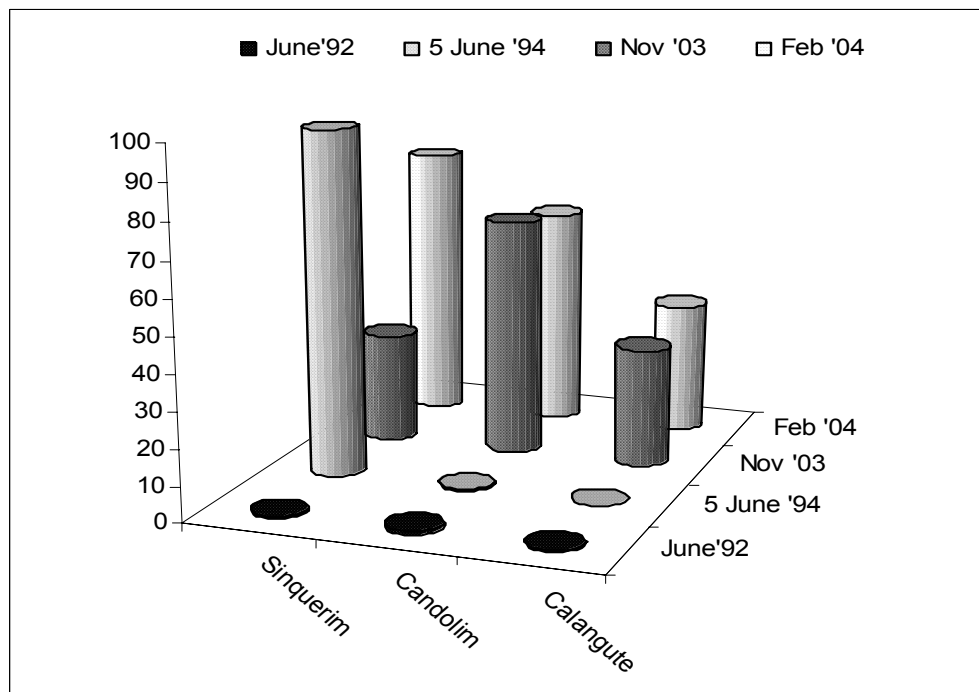


Fig. 5.2: Variation in PHC concentration at Sinqerim-Calangute- Candolim (1992-2004; redrawn after Ingole et al., 2006)

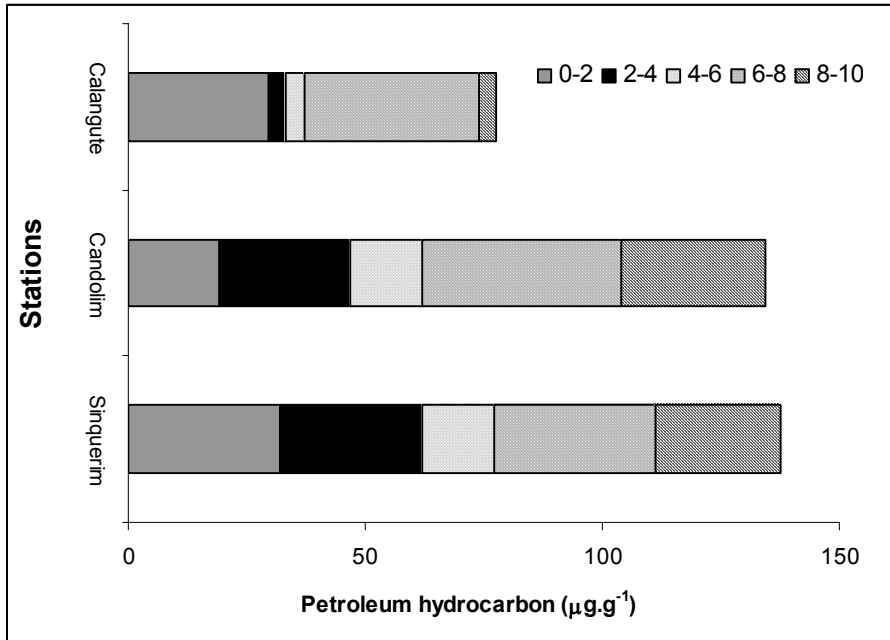


Fig.5.3: Vertical distribution of petroleum hydrocarbon in and intertidal beach sediment

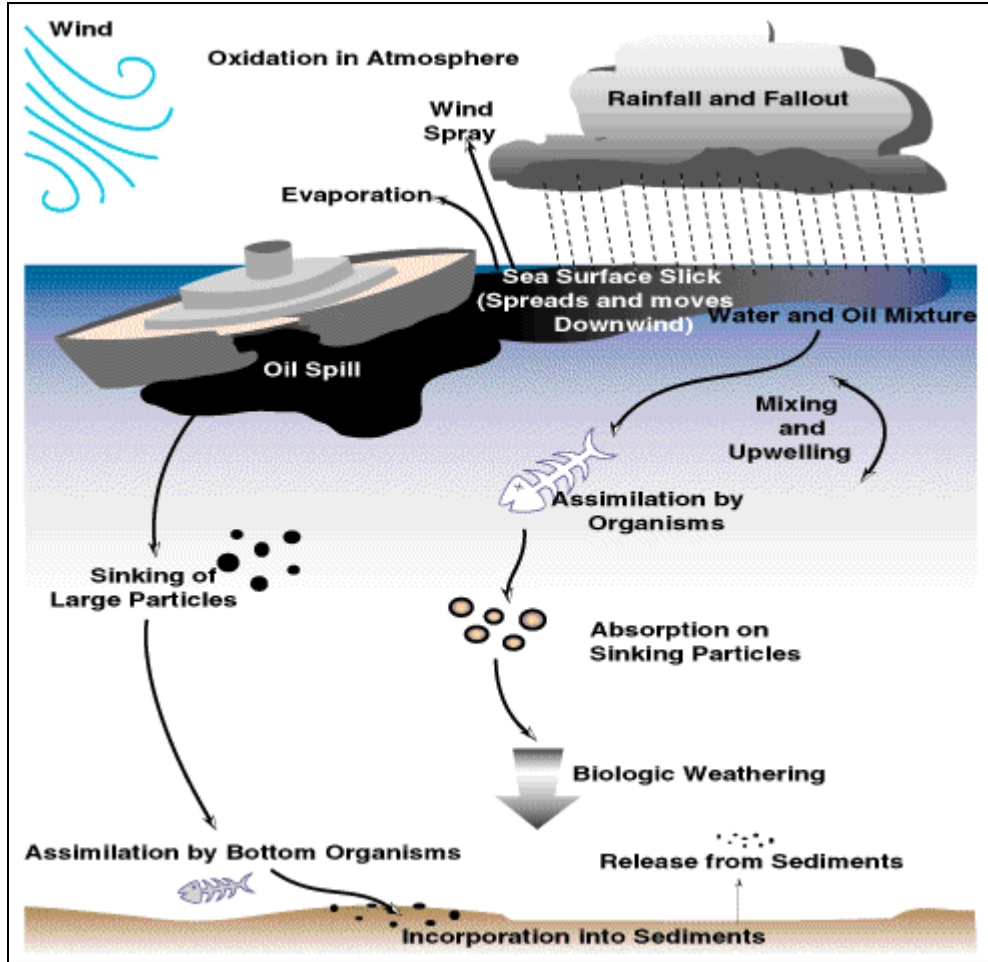


Fig 5.4: Fate of spilled oil in the marine environment
 Source-www.see-the-sea.org

Plate 5.1



Plate 5.1 A: Oil Spilling from “MV Ocean Seraya”.

Source-www.indiancoastguard.nic.in



Plate 5.1 B: Clean up of tar balls at Polem

Source-www.indiancoastguard.nic.in

CHAPTER 6

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