GENERAL CONSIDERATIONS

"Everything is connected to everything else. Everything must go somewhere. Nature knows best. There is no such thing as free lunch. If you don't put something in ecology, its not there"

Barry commoner

It is widely appreciated that the ecosystem functioning is dictated to a large degree by biodiversity and the community structure that result from factors such as the richness and evenness of the diversity. Hence, the earth's most valuable resource today is the diversity of its biological capital or the "Biodiversity". Biodiversity is a popular way of describing diversity of life on earth. It includes all life forms and the ecosystem of which they are part off. The more biologically diverse the ecosystem better the chance of all species have for their survival. Human however, abuse much of these resources in order to accomplish economic success. However, this success comes at the expense of humanity's future. The resources on the planet Earth have the potential to sustain life indefinitely if used with caution. However, when exploited, the resources can be lost forever. Recently humans have become aware of the importance of this precious resource and have taken action to preserve biodiversity through laws, regulations, protected areas, and funding. While the conservation actions taken thus far are constructive, most of the effort was directed towards terrestrial ecosystem.

One major habitat that is under serious threat from human activities is the aquatic habitat. Many global conservation organizations, including RAMSAR convention, have identified the aquatic biodiversity to be the most threatened of all the biodiversity. Despite its critical status worldwide, marine biodiversity has not gained attention afforded to other rudiments of biodiversity (Seshagiri and Anil, 2003). Accelerated loss of coastal and marine biodiversity components over the last few decades has been of great concern. Environmental changes, over exploitation and habitat loss are amongst the major causes of species loss that, according to certain estimates, is of the order of a species per day (Chee, 2004). It is however, not known what fraction of this loss is from marine environment, a situation owing to lack of systematic coverage of all faunal and floral classes with the prominence placed often on economically important groups or habitats (Christie *et al.*,

2006) Thus, the importance of conserving marine biodiversity has been only recently realized and consequently very little action has been initiated.

India is one among the twelve mega-biodiversity countries and twenty five hotspots of the richest and highly endangered eco regions of the world (Myers *et al.,* 2000). The pollution of sea and oceans, and also of other water bodies has got augmented at an unprecedented scale, that the survival of hundreds of marine species of plants and animals is gravely endangered especially in India. Pollution of coastal waters through human activities has drastically altered the biodiversity (Thorne, 1999). Industrial effluents, thermal and freshwater discharges, land reclamation and other anthropogenic effects have caused much damage to coastal diversity all over the world. In the context of the Indian scenario, large-scale destruction has occurred at the marine ecosystem. The massive destruction of coral reefs in the Gulf of Mannar and Gulf of Kutch are well known examples (Qasim, 1998 and Sen Gupta and Desa, 2001)

Ocean waters serve as a source of food and valuable minerals. The ocean influences several elements of the various aquatic and terrestrial habitats, including various climatic conditions on the earth. Interestingly, people are turning to the oceans for many specific reasons e.g. for food, medicines, minerals, pearls and for extracting the energy source in the form of hydrocarbon compounds etc. In addition to all, ocean is the home for myriad forms of life beneath and above the waters. The marine ecosystem is also act as source of food for many seabirds.

In the present study, the flora and fauna of the three coastal locations *viz.* Diu, Veraval and Alang of the Saurashtra coast have been studied. The Saurashtra coastline (Western part of India) is having a broad continental shelf harboring very rich biota including wide variety of marine fauna, some of which are economically very important. The coastal zone of Gujarat like their counterparts is subjected to dual act of pollution and over exploitation of its resources. However, in past few years, the three flourishing cities under the Saurashtra belt *viz* Diu, Veraval and Alang have added much scientific attention for several legitimate reasons. These three cities, due to the rapid industrialization and recreational activities, are susceptible to all levels of contamination, which are manifested to its ecological unit especially marine ecology. The major causes of contagion in these locations are mainly due to operational and accidental discharge of ship born pollutants, disposal of sewage from the

local areas and discharge of untreated and treated effluents from many of the small and large scale industries in the nearby areas. Veraval with many fish harboring centers, fish cleaning and packing industries produce liters of organic waste which are dumped directly in the sea. Diu also produces large amount of waste from its recreational activities, especially from many of the Hotels and Motels situated nearer to the coast.

A survey through the available literature revealed that only very few studies have been carried out related to the ecology and biodiversity of the Suarashtra coast and further, even limited studies focused on its deteriorating environmental conditions. Hence, a need was felt to carry out a composite study, enlisting the existing microflora and fauna of the three selected stations of the Suarashtra coast and identifying the dominant zooplankton and phytoplankton community. The study also focuses on the various anthropogenic activities prevailing in the three stations *viz* Diu, Veraval and Alang and its negative impacts on the plankton species. The overall plankton community structure and their response to seasonal variations in the hydrological factors were also analyzed.

The physicochemical parameters of the three locations show seasonal variations. The water quality parameters such as pH, salinity, DO, BOD, TDS, nutrients ($NO_2^- - N$, $NO_3^- - N$, $PO_4^{3-} - P$, silicate) and chlorophyll – a all exhibited seasonal variations. Planktonic communities in the coastal zones of the Saurasthtra are found highly diverse. However, these communities might be sensitive to environmental changes since any subtle changes in the environment could elicit a non-linear response. The three study station *viz.* Diu, Veraval and Alang exhibited a total of sixty eight species of plankton both zooplankton and phytoplankton. Some of the species occurred only in particular season and whereas some of the species were observed through out the year. There are a few species which were observed only at a particular station. There observed as many as 30 species of phytoplankton belonging to seventeen families. Similarly, 38 species of zooplankton belonging to twenty two families were documented.

Amongst the three stations, Diu supported a good diversity of plankton species followed by Veraval and least diversity was encountered at Alang. As stated earlier, copepods figures as the dominant zooplankton community at all the three selected stations. Species belonging to the copepod families *Paracalanidae, Calanidae, Oncaeidae* and *Centropagidae* were

common in the three study stations. Goswami (1983) and Achuthankutty *et al.* (1997) also recorded copepods as the most dominant species at the coastal waters of Goa. The other taxonomic group recorded were Forminiferans, Appendicularians, Chetognaths, Siphonophora, Harpacticoida, Cyclopoida, Decapods, Rotiferans, Gastropods, fish egg and post larva of fish. The four species of copepods e.g. *Rhincalanus, Parancalanus, Sagitta enflata,* and *Sagitta sp* were perennial and found in all the sites.

Besides, some of the species were recorded either all through the season or during specific season of the year. In Diu *Cladocearns, Harpacticoids, Appendicularians, Cyclopoids* and *Foraminiferans* were found as dominant groups, collectively adding up to 45.53%. The order copepod characterized by *Paracalanus* sp (15%), *Rhincalanus* sp (14%), *Isias tropica* (8.46%), and *Acrocalanus gracillis* (8.35%) relatively outsized other species at Diu. The marine zooplankton community included a few opportunistic species that were exclusively found in any of the three stations e.g. *Keretella* sp, *Hippopodius* sp, few foraminiferans like *Globegerina* sp, *Rosalina* sp and Zoea larva together attributing up to 1.73 % of the total number of species of the zooplankton community excluding *Chetoganaths* sp solely recorded at Alang. The community composition of the plankton population also included 30 species of phytoplankton belonging 3 divisions, 3 classes, 6 orders and 17 families. Chrysophyta were the most dominant group (23 species), followed by, Cyanophyta (3 species) and Phyrophyta (4 species), among all *Coscinodiscus* sp was the most abundant and persistent throughout the seasons.

Diu, Veraval and Alang together support a good diversity of plankton population seasonally along the coastal zones of Saurashtra. The monsoon and post monsoon recorded the maximum diversity of phytoplankton and zooplankton. However, the highest species diversity, as indicated by Shannon-Wiener diversity, was observed during the post monsoon. The species number during the post monsoon season was maximum. Least species diversity was observed during the pre monsoon season. The seasonal changes were more prominent, with an increase in the zooplankton and phytoplankton population during the monsoon and post monsoon season (Seshaiyana, 2006). Raman *et al.* (1975) stated that plankton show rich diversity during the monsoon and the post monsoon season.

Ecological succession is a slow process of change in the number of individuals belonging to species of a community or of the establishment of the new population. In the latter case,

the new species may gradually replace the original inhabitants. This process is widespread in marine plankton communities and is mainly associated with the seasonal changes in the hydrogarphy. Yoshinnaga *et al.,* (2001) opined that animal populations live in diverse environments, and a complex mixture of environmental factors regulates their population dynamics. In the present study, it was observed that abundances of many species exhibited strong correlations with environmental variables especially various physicochemical parameters. Further, pronounced diel and seasonal patterns of distribution bring in temporal variations and inter annual variability among the community.

During the present study, seasonal variations in the dissolved nutrient contents tend to bring temporal variability among the phytoplankton population, composition and diversity in the coastal waters of the Saurashtra. The overall phytoplankton community, showed a characteristic temporal variation in the density at all the four seasons of the year during the study period. As stated, a definite periodicity has been observed in the phytoplankton density, which showed a gradual increase from winter to monsoon, though a perceptible drop in density was evidenced during the pre monsoon season. This may be attributed to the decrease in the essential nutrients concentration required for the growth of the phytoplankton cells. Therefore, nutrient concentration is considered as an essential requisite for the productivity in the oceans that would also expansively affect the zooplankton community.

Therefore, to understand the influence of these dissolved nutrients on the phytoplankton community in general (Chapter 3) that brings in temporal and spatial distribution, the data was subjected to statistical study, which includes One Way ANOVA followed by Tukey's analysis and Analysis of similarity (ANOSIM). These tests were performed to analyze, which nutrient is principally contributing to bring in temporal variability among the community. The results showed that among the nutrients the oxidized nitrogen and phosphate phosphorus seems to have a considerable effect on the overall diversity of phytoplankton at Diu and Veraval respectively. In Alang, nutrients except silicates could not evoke any significant effect on the community diversity. The ANOSIM test specified a significant correlation between the dissolved nutrients and the phytoplankton community, thereby inducing temporal variations within the community of the three stations. By and large, maximum diversity was in monsoon at Diu and least during summer season at Alang. Although pinnate diatoms dominate the three stations, individual distinctiveness indicates

that centric diatom particularly *Coscinodiscus sp* were the most dominant at all the three study stations during the four seasons.

The hydrological parameters, if vitally studied in marine waters, phosphorus and nitrogen are considered to be the limiting factors for the phytoplankton growth. In Diu the values of phosphate was high through all the seasons as a result of recreational activities, due to dumping of partially treated or untreated sewage waste into the water. The lowest phosphate levels were encountered during pre monsoon at Alang while the highest values were noticed during post monsoon season at Diu. Thus, it could be presumed as the reason for phytoplankton diversity and consequently zooplankton diversity during post monsoon season. Coastal upwellings in the oceans are responsible for the inflation in the nutrients including inorganic phosphate especially during post monsoon season (Radhakrishna 1969). Manimaran *et al.* (1997) recorded prominent peaks in the distribution of total phosphorus during monsoon and post monsoon season from fish harboring area of Tuticorin. However, Arun (2005) observed a variation in phosphate level showing an increase in concentration during pre monsoon at Cochin estuary.

In case of total oxidized nitrogen and silicates, total oxidized nitrogen showed its highest mean values at Diu. On the basis of the seasonal variations the highest value was recorded during winter at Alang. This may be probably due to remineralization, varying load and dynamic water exchange at the coastal waters of the ship breaking yard. The report from the Finnish Institute of Marine Research, states that irrespective of the other characteristic in the Gulf of Bothenia Bay, the total nitrogen concentration was high during all the seasons of the year. Supporting, the above statement, Ogilvie *et al.* (1997) recorded maximum concentration of dissolved nitrogen during winter with low temperature in River Colne estuary in United Kingdom. However, as the other two stations Veraval and Diu are concerned, the highest values of total oxidized nitrogen were seen during the monsoon season. Accordingly, high zooplankton and phytoplankton diversities were documented with a general rise in nitrate value during monsoon season. Arun, (2005) observed that, the onset of Southwest monsoon was accompanied by a general rise in the nitrate level along with increase in other nutrients in Cochin estuary.

The monsoon and post monsoon season recorded an increase in silicate concentration at all the three stations of the Saurashtra coastline. The high concentration of silicate

successively coincided with the abundance of *Rhizosolenia, Nitzchia, Navicula* and *Coscinodiscus* during monsoon and post monsoon seasons. There occurred a great deal of variation in silicate concentration in monsoon at Alang. Though silicate indicated a great increase, no corresponding escalation in diatoms was observed in monsoon. These factors brought in temporal variability within the community structure of phytoplankton population. Overall, the highest number of phytoplankton has been observed at Diu. A total of 22 species belonging to 5 orders and 14 families are recorded from this station during the study period. This is followed by the second station Veraval that harbored a total of 18 species belonging to 4 orders and 13 families and lastly the Alang with 15 species belonging to 5 orders and 10 families.

This distribution pattern of the phytoplankton influences the higher trophic levels in the community especially the primary consumers, the zooplankton. With the variations in the phytoplankton populations, in accordance with physicochemical parameters, the zooplankton population showed corresponding alteration in its density. This change also affects the performance of individuals at various stages in their life history cycle *via* changes in physiology, morphology and behavior (Hochackka and Somero, 2002). Therefore, there are many possible strategies that regulate the composition of community and were evaluated using multivariate ordinations to understand the relationship between the community composition and environmental variables (Chapter 4).

The zooplankton distribution among the three stations indicated thirty seven species of zooplankton belonging to 7 class, 8 orders, 22 families and 37 genera. The qualitative and quantitative analysis of zooplankton species revealed that copepods were the most diversified group comprising of 25 species followed by formíniferans 4 species, appendicularians 1 species, chetognaths 2 species, siphonophora 1 species harpacticoida 2 species, cyclopoida 5 species, decapods 2 species, rotiferans 1 species, Gastropods 1 species, Pisces 1 fish egg and 1 post larva of fish. In spite of large number of species recorded, only four species were perennial *viz. Rhincalanus, Paracalanus, Sagitta enflata* and *Sagitta* sp. Many of the species of zooplankton are found to be exclusive in particular sampling station. Two species in Diu, five species in Veraval and five species in Alang were exclusive among the 37 zooplankton species recorded during the tenure of the study. These exclusive species constitutes 5% in Diu, 15% in Veraval and 12.5% in Alang. Apart from the exclusive species, some species of zooplankton occurs throughout the year

irrespective of the season and they are termed as the common species. Copepods like, *Acrocalanus, Paracalanus* and *Calancalanus* were the most common species.

To further understand the dynamics of ecological system following perturbations or disturbances in marine ecosystem, multivariate ordinations were performed taking in the data matrix. Four different variables were used to explain the complete community compositions, its complexity gradient and the variations in the community dynamics as result of hydrological changes in the costal waters of Saurashtra. The Bray-Curtis Euclidean distance was performed to measure the similarity index expressed in dendrograms and Principle component analysis to measure the faunistic difference between the communities. In order to quantify the changes at the taxonomic level the Taxonomic Distinctness Analysis was performed. The zooplankton species were also subjected to variability in habitat parameters (Temperature, pH, DO, Salinity, TSS etc), consequently, to understand the effects of each individual parameters on plankton community compositions, Draftsman's Correlation Analysis was also carried out.

The multivariate analysis using similarity indices revealed that highly dominant species shared the greatest distance in the cluster plot. While the rare species formed, the moderate distance and few of the exclusive species, found only at particular stations and seasons, shared the shortest distance within the community. In all the three stations *Parancalanus, Rhincalanus, Isias tropica, Acrocalanus gracillis* Fish egg, *Isias tropica* and *Calocalanus gracillis* which are found dominant shared the highest distance in the dendrograms. *Temora* sp, *Nonion, Calanus,* Mysis of *P. indica, T. discaudata, Pleuronema gracillis* and *Centropages elongata* and *R. cornutus Sagitta enflata, Sagitta sp,* Larva of barnacle *and Oithona brevicornis* generally shared moderate distance as they were rare species, and were encountered more during a particular season of the year in the present study. Few of the opportunistic species, *Microsetella, Microsetella gracillis, Karetella,* siphonophores, cyclopoid nauplii foraminiferans, *Globegerina* and *Rosalina* all together shared the shortest distance between themselves in the community. The data matrix further subjected to PCA ordinations which indicated the amount of variations in the community, and are measured as the faunistic distinctions between the different communities. This indicated species that directly or inversely responsible for causing 50%, 30% and 20% variations among the communities. *Acrocalanus, A. gracillis, I. tropica, Paracalanus, Oikopleura, Rosalina, Nonion, Microsetella, M. gracillis, Gyrosigma* and *Navicula* all directly or inversely

contributed to 50 % variations in the community. Similarly, *C. nauplius, Euchaeta, Sagitta enflata, Sagitta sp* and *Calanus* species inversely brought in 30% variations in the overall community structure, for all the three stations of the Saurashtra coast. The 20% variation reveals a trivial amount of community difference, which may not be worth interpreting. However, the factor correlates directly to copepods.

The analysis with PCA indicated a community change among stations within time, perhaps because of changes in hydrological properties. However, the Taxonomic distinctness test further reveals the shifts in the taxonomic relatedness of the assemblage (Warwick and Clarke 1995). This denotes that, at all the three stations, zooplankton belonging to single phylum Arthropoda were the most dominant. This further reflects the taxonomic spread of species among the community (Clarke and Warwick, 1999). The funnel and ellipsoidal plot notify that all the samples fall within the 95% confidence contour. This suggests the, probability of the all the species drawn from the same regional species pool, while the taxonomic spread was concentrated in to a few taxa (Genera and families). This also indicates an overall representation of some taxa and the under representation of other in the overall community composition. This includes both the dominant forms and the exclusive one showing the overall representations, and some trivial divisions like Rotiferans and Protists that was under represented.

Plankton community showed seasonality in occurrence. Many factors are responsible for plankton community to show seasonal succession (Gasi naite *et al.,* 2005). Variations in the physicochemical parameters also attributed to this seasonality in plankton community (James *et al.,* 2003). Margalef (1978) and Samyda (1980) from intensive study of the diatoms in the Baltic Sea suggested that some essential factors such as physical, chemical limitations, high turbulent environment and high nutrient concentration regulate phytoplankton succession. Whereas, Paula *et al.* (1988) explained that zooplankton distribution in the coastal waters are influenced by tidal currents, salinity gradients, phytoplankton population, competition and predation. Hence, it could be possible that the changes in the season that affect the quality of water, might be affecting the plankton community as well. In, addition to this, biotic impacts of predation, food and habitat could be other factors influencing the structure and composition of the community.

However, seasonal changes in other physicochemical parameters of the water also brought

in some observable changes in the population. In the present study, community changes of the zooplankton assemblage with seasonal variations in the hydrological changes were monitored. Further, regression analysis using Draftsman's plot was carried out. It can be seen that dissolved oxygen, salinity and chlorophyll-a showed a significant positive correlation with zooplankton abundance. This suggests that zooplankton diversity/density is much affected by variations in these factors. However, the temperature showed a negative relation to the overall density of zooplankton species. This indicates, temperature has been described as the important factor in determining the zooplankton community. de Souza lima and Williams (1978), Turner (1978) and Hoppkinson (1985) stated that temperature have a pronounced effect on the metabolism of the residing organisms in a marine ecosystem. Variations in the plankton community for several coastal ecosystems have been largely explained by variations in the water temperature. In the present study maximum density was observed when the temperature becomes moderate at Diu, Veraval and Alang. The zooplankton showed a drop in its density as the temperature rises in pre monsoon, similarly in winter when the temperature falls drastically, a subsequent decrease in the zooplankton population has been observed. It could therefore be surmised that the zooplankton needs an optimum temperature for survival and when the temperature varies from the optimum, the zooplankton population decreases drastically. The effects of temperature on zooplankton populations have been often linked with biotic effects such as increase in some of the species of copepods like *Eucalanus spp* and *Acartia spp* during NE monsoon with a drop in temperature and slight decrease in salinity (Madhupratap, 1980, Baidya and Choudary, 1984 and Tiwari and Nair, 1993). Thus, it could be deduced that temperature does not solely decide when and where a species will occur. Its influence is mainly indirect enhancing or retarding development and function in tandem with other biotic and abiotic factors.

In the past, pH has not been considered as an important chemical parameter influencing biotic processes in marine environments. However, a number of studies have shown that variations in the pH can affect the plankton growth in number of ways. It can change the distribution of carbon dioxide and carbon availability, alter the availability of trace metals and essential nutrients and at extreme, the variations in the pH may potentially cause physiological effects (Celia and Edward, 1994). The present study showed that, the pH value ranged between 7.8 and 8.26 indicating that pH is neutral to alkaline. This is in agreement with the observation of Hinga, (2002) who opined that pH of the World's Ocean

remains between 7.5 and 8.5. The pH in typical coastal environment may vary by 1 or more pH units. Regression analysis showed an inverse relation with zooplankton abundance, thereby stating that, with the increase in pH, the population may show decrease in trend.

The concentration of dissolved oxygen is very important for all marine forms. It also plays a significant role in supporting all the biological community of the marine habitat (Best *et al.,* 2006). In the present study, the dissolved oxygen exhibited a consistent variation annually. The minimum dissolved oxygen of 2.83mg/L was recorded at Alang. Where as coastal waters of Diu showed the high oxygen concentration with mean values of 5.59mg/L. In Veraval, mean dissolved oxygen concentration of 4.67mg/L was noted during the entire course of study. The zooplankton abundance and chlorophyll – a was directly related to DO which are basic requirement for the survival of any organism. In Mumbai Harbor waters, it was observed that the tidal flow had largely influenced the polluted Bay waters, where at least one third of water is renewed at every tidal cycle. This helped to maintain normal dissolved oxygen level and reduce organic load for zooplankton to survive (Swane *et al.,* 2001). Andrea and Jean (2004) from their observations found that zooplankton community is directly proportional to the dissolved oxygen. Further, they observed a decline in the zooplankton population in winter, attributing to combined effects of many factors.

Salinity also influences the community structure of plankton. Sankaranarayan and Qasim (1969) and Quasim *et al.* (1972) indicated that coastal waters show increased plankton production due to reduction in salinity and are tend to utilize enriched waters. In the present study, also the salinity exhibited a direct relation with zooplankton abundance. The concentration varied from minimum value of 31.6‰ at Alang to a meager increase up to 32.4‰ at Diu. Veraval, though showed a annual salinity gradient of 32.0‰ during the study. Arthur (1960) reported about the zooplankton tolerance capacity to constant changes as high and low salinities in the Caribbean Sea and South Atlantic Ocean. The majority of forms studied withstand salinity changes much greater than they would be expected to encounter, thus suggesting that salinity may not be a limiting factor in their distribution. Moreover, the salinity showed a positive correlation with chlorophyll – a at all the three stations *viz.* Diu, Veraval and Alang. Mallin (1994) reported the underlying influence of salinity on productivity in estuaries on the east coast of United states. Gessner and Schramm (1971) suggested the importance of salinity as an ecological factor in controlling

the abundance of phytoplankton organisms in estuaries. However, since the factors influencing the productivity are many a more detailed investigation has been performed to consider the statistical significance of various environmental parameters on the plankton productivity, of the coastal waters of Saurashtra coast.

The total suspended solids (TSS) is another important factor, which determines the community structure of the marine plankton. The total suspended solids in water may reflect the turbidity characteristic of eroding coastline or the entry of many of the suspended materials into the seawater as surface runoff mainly as industrial effluents, agricultural and sewage waste. The increase in total suspended solids strongly affects the light attenuations, which further affect the chlorophyll – a concentration in seawater. In the present study, total suspended solids exhibits a negative correlation with chlorophyll-a and zooplankton This is in agreement with the findings of Dunton (1990) who described that variations in transparency of water due to turbidity can have significant effects on the annual production of different species in the marine waters. The increase in the turbidity of water may affect the chlorophyll – a concentration, which subsequently affects the zooplankton composition. In the present study Diu recorded the maximum chlorophyll – a with a subsequent increase in the zooplankton density. Veraval to Alang exhibited a negative drift in annual chlorophyll – a concentration with a consequent decline in its zooplankton population and thereby affecting its community dynamics. Overall, Diu which has relatively low suspended solids has the highest zooplankton and phytoplankton diversity, as compared to Veraval and Alang with high suspended solids.

Besides, the effect of variations in the physicochemical factors including nutrients on the plankton community, there exists other environmental variables that affect the plankton community. The problem of marine pollution due to various types of anthropogenes such as organochlorine pesticides (OCP), polychlorinated biphenyl(PCBs), polyaromatic hydrocarbons (PAHs), petroleum hydrocarbons (PHCs), heavy metals (mercury, cadmium, arsenic, cobalt, manganese etc) and nutrient salts has become a global concern. Rapid industrialization and attendant discharge of pollutants gave rise to deterioration in the quality of water. In the present study, the coastal areas of the three stations *viz* Diu, Veraval and Alang are found greatly under pressure due to pollution from various sources. Hence, the coastal zone of the Suarashtra was assessed to comprehend the effects of one of the major anthropogens the petroleum hydrocarbons PHCs (Chapter 5).

Diu, known for its recreational centre, is one of the leading tourist centers of Gujarat. Tourism has affected the coastal regions to a great extent with pollution mainly cropping up from the recreational centers like Hotels etc. The hotels in Diu, mainly dumps or discharges the sewage and culinary waste into the sea causing contamination in the Sea. The hydrocarbon concentration in Diu waters ranges from a minimum concentration of 22.0mg/L to a maximum concentration of 27.25 mg/L. The BOD levels at Diu were comparatively less with a minimum value of 3mg/L suggesting a less organic load in the sea waters. Günay (1989) reported about the different impacts of coastal tourisms on the marine environment of the two coastal, cities of Turkey, causing serious health problems due to the presence of the coliform bacteria concentration in water.

The other site Veraval is the largest fishing harbor in Gujarat and many have taken to fishing as their main occupation. However, the boats and steamers used for fish catching are in dilapidated conditions, therefore it results in the leaking of the diesel and other heavy metals, paints and other anti fouling agents from the these small boats and ships in the waters leading to heavy pollution. Besides, the fish handling methods used by these fishermen are very poor. At landing stations fish are thrown on sand at the beach where they are gutted and de-scaled, the offal is left on the beach to decompose, thus becomes a source of contamination in water. Due to shortage of fresh water at these stations, fish are washed with seawater, catches pile on the sand under high temperatures, increasing the decomposition rate. The BOD levels at Veraval were 5mg/L and the PHCs ranged from a minimum concentration of 24.0 mg/L to a maximum of 28.2 mg/L. However, the Central Pollution Control Board (2003) gave the report that the oxygen content in the harbor water was much less and sometimes it reaches to nil. The water of the harbor area becomes pink in color due to mixing of sewage and effluents. High concentration of petroleum hydrocarbon was observed in the harbor water due to high traffic of fishing vessels and flushing of port basin.

Ship breaking is an important activity along the West Coast of India especially in Gujarat. Alang, a small coastal town in the state, houses the world's largest ship breaking yard (Marruf and Islam, 2006). Forty five thousand workers, it is estimated, breakdown about 200 ships in this yard each year. This produces 2.6 million tons of scrap steel per year; equivalent to 15% of the country's total steel production. Ship breaking industry creates

numerous hazards for the coastal and marine environment (Tiwari *et al.,* 2001). Due to the activity of ship breaking large number of dangerous pollutants including toxic waste, oil, polychlorinated biphenyls and heavy metals releases in to the water and to the seabed. While most of the oil is removed before a ship is scrapped, sand used to mop up the remaining oil is thrown in to the sea (Islam and Hossain 1986). High concentration of oil and grease are found in the coastal waters, choking marine life. In the present study, the mean values of BOD remained higher at Alang (5.9mg/L). Similarly, Hossain (1983) reported substantial increase in BOD contents from the ship breaking yard of Bangladesh. The PHCs concentration at Alang ranged from a minimum of 26.2mg/L to a maximum concentration of 29.4mg/L. Moreover, the concentration of PHCs in the coastal waters of all the three stations showed variations with respect to seasons. Mean comparison of biological parameters and PHCs were analyzed using Tukey's test for all the three stations in order to understand the significant effects of hydrocarbons on the flora and fauna of the Sauarsahtra coast.

It is apparent from the study that any unprecedented change induced due to various activities like tourisms, fish harboring and ship breaking activities contaminate the coastal soil and the sea water environment and thus impair ecological settings. In the present study, PHCs concentration exhibited variations in the species diversity and richness of the plankton community. Diu showed increase in the species diversity than that of Veraval, with a diversity of 1.30 and richness of 0.26. The diatoms dominated over the dinoflagellates suggesting a greater tolerance of diatoms to high PHCs contents in the seawater. However, low diversity and richness for the phytoplankton population was reported from Alang that receives high hydrocarbon contents from its ship breaking activities along with heavy loads of sewage as well as other inorganic wastes. The Alang was observed to sustain predominantly centric diatoms like *Thalassiosira* and *Coscinodiscus sp.* However, Siddique (2004) observed presence of *Coscinodiscus, Clostratrum* and *Zygnema* from the sites contaminated with hydrocarbons. Further, it was observed that the abundance and occurrence in number as well as species richness was very poor in the ship breaking area.

In general, the petroleum hydrocarbons can inhibit the growth of either phytoplankton or zooplankton, or else can also inhibit the growth of total plankton as well (Chen 1998). However, zooplankton population at Alang showed considerable drop in numbers than

compared to other two stations - Diu and Veraval. The zooplankton, which are rather most sensitive to petroleum hydrocarbons in seawaters were observed low in number when the hydrocarbon content showed an increase in trend at all the three selected stations. The Chaetognaths has been noticed to be successfully thriving in the Alang waters in spite of increase in PHCs content. Whereas in Veraval and Diu copepods were reported to be a major groups with low species diversity indicating stress due to various anthropogenic compounds including PHCs in the seawaters. Siddique (2004) reported low abundance of zooplankton. Furthermore, Oleg (1968) indicated that hydrocarbon products, especially oils, exert detrimental effects on the hyponeuston (community near the water surface) eggs and larvae of fish e.g. (*Rhombus maeoticus*) phytoplankton and zooplankton, nektonic organisms including adult fishes (*via* direct damage or by causing them to emigrate). Additionally, Mironov (1980) studied on the composition of Black Sea mussels, *Mytilus galloprovincialis* and specified that the hydrocarbon compound get concentrated in the mussel tissue of the lower marine fauna, and thereby bound into faeces and pseudofaeces which contain greater percentage of aromatic compound than the oil initially present in the seawater.

Thus, it can be deduced that by and large Diu seems to have less tainted water, thereby providing a better habitat for the plankton community. Moreover, the levels of dissolved oxygen are relatively high at Diu, with lesser BOD and high primary productivity, which is indeed needed for the survival of zooplankton species. Veraval and Alang too seem to be promising habitat for the survival of varied microfauna and flora due to its high tidal influence and continuous mixing of the seawaters. Additionally, dissolved oxygen is fairly present at Veraval and Alang even though BOD levels increases during some seasons of the year. Besides this, dissolved nutrient concentration is also quite high at some season leading to algal bloom, thereby providing better opportunity for diverse zooplankton species. These factors could be the reason for high species diversity at Veraval as well as high number of exclusive species at Veraval and Alang.

In the light of the present observations and subsequent analyses, it can be summarized that, both the abiotic and biotic factors at each study site might be interacting with each other resulting in a characteristic composition of community when at equilibrium. Nonetheless, any change in the former results in appropriate alteration in the structure of the later. Moreover, the findings of the present study could be utilized as an inclusive baseline data

to asses and monitor the temporal as well as the anthropogenic amendments on the marine ecosystem, as any changes in the abiotic component of the ecosystem will be altering the structure of the existing biota. In conclusion, oceans are the indispensable fraction of the very existence on the earth. Its biodiversity is more essential to the survival of all life forms in this universe. The loss of ocean biodiversity is more than just an esthetic issue it portends significant consequences for human health, economic and food security.