CHAPTER 1

"Shades of green and aqua blue
The sea painted a thousand hues.....
.....To the God of creation and of the sea
A sea being robbed by cruel thieves
The whale song drifts silently away
The hands of man have silenced their praise
As God looks down in his majesty
As tears trickle down on the silent sea."

Debi Fields

INTRODUCTION

All life on earth is a part of one great interdependent system. It interacts with and depends on the living and non-living components of the planet earth (McClendon, 1999). Upholding life, on this planet is the greatest challenge the humanity faces until to date. Plants, animals, microorganisms and the physical environment all interacts together with one another within the ecosystem. This forms the foundation of the sustainable development. This blend is very dynamic both in time and in space and is constantly changing, unfolding and producing new combinations. The living elements, living by nature and their capacity to self reproduce come in a great variety of shapes and complexity that are constantly changing and evolving, comprising the diversity of life. Today diversity at all the levels on various habitats of planet earth is endangered (Biles, *et al.,* 2002)

Diversity is an asset not an entity in itself (Brown, *et al.,* 2001). It focuses on the variety of life and its diverse processes varying from one another in one or more characteristics. However, it is attributed to all living things in the universe which are unique in themselves e.g. no two organisms are indistinguishable to one another. The origin of this variability is to be found in the basic and fundamental property of the genetic material (Claes, 1998). This characteristic combined with natural selection allows the acquisition and accumulation of favorable mutations. Approximately three thousands years of existence of life on the earth, these processes have produced enormous biological variations that we witness today,

which is at best of only a very diminutive proportion of all the variations that existed in the past.

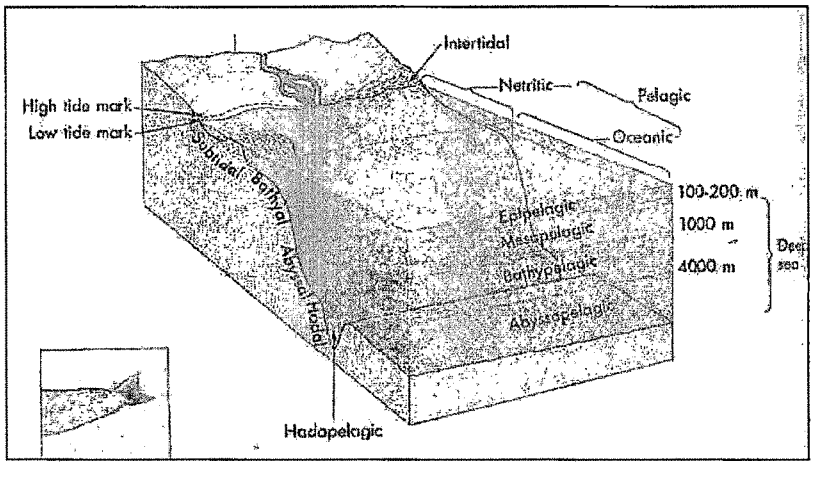
Regrettably, this diversity of life is at risk by human endowments, although the exact rate of species loss is difficult to ascertain. In addition, species loss is only one aspect of the profound transformation that is taking place, brought about by the growth of human population and their economic activities (Sorbrig, 2000).

For years conservationist and biologists have given great attention for understanding the various confinements of ecosystems. However, the convention of the Biological Diversity adopted at the Rio Earth Summit in June 1992, has led to resurgence of interests in the subject of biodiversity and its various human dimensions (Heywood and Watson, 1995; De Castric and Jounes, 1996). The convention requires *inter alia,* an assessment of the status of biodiversity in all the countries and formulations of integrated strategies for its conversation. Unfortunately, in some of the countries, such as India, even an appraisal of the status of biodiversity has not been totally completed until now, while much outcry is spawned about the need for the conservation and legislative action on issues concerning biodiversity. Its now widely appreciated that ecosystem functioning is dictated to a large degree by biodiversity and community structure of different species in an ecosystem. In the decades, biodiversity of the terrestrial ecosystem has received a great deal of attention from the scientist throughout the globe. Whereas, the aquatic ecosystem, where life originated, remains uncared up to a certain level of its existence. However, increasing concern over the distribution of habitats, bioinvasions and alterations to the diversity of various life forms, made ecologists and biologists necessary to understand the relation between biodiversity and ecosystem functioning in the entire aquatic bionetwork over the planet. Amongst the entire aquatic system, there is a broad scientific agreement that marine biodiversity all over the world's oceans is seriously in jeopardy.

The oceans cover more than 70% of the earth surface or about 36 million km^2 forming a skin of thousands of miles across. The environment beneath is so complex, it is divided in to subunits called zones (Figure 1.1). The open water environment is the pelagic zone, and the seafloor environment is the benthic zone. The pelagic zone is divided into the coastal or nertic zone or deep water away from the influence of land. The surface, where there is

enough light intensity for plant growth, is known as the photic zone, and can extend through both the nertic and oceanic zones. Deeper zones where almost no sunlight penetrates is represented by the dyphotic zone (twilight) and the aphotic zone (no light).

Figure 1.1 Zonations in the ocean



In spite of the distinction in the underneath of the massive water body, the life originated in water approximately 3.8 billion years ago. This makes the Ocean unique in its physical, chemical and biological features. From the shores to the deepest depth; it's a highly complex ecosystem providing diverse environment for the sustenance and procreation of the myriad life forms, where they exits from giant blue whales to microscopic miniature life forms of wanders known as Plankton.

WHAT IS PLANKTON?

The word plankton originates from the Greek meaning "Wandering". 'Plankton' as a term was first used by Victor Hansen (1887) for the aquatic communities of floating and rifting organisms that are carried primarily by movement of water current rather by their own swimming ability. While this is so, it must be remembered that, considering their small size, many plankton animals are strong swimmers and are capable of moving through relatively long distances over a period, particularly in a vertical direction. Plankton includes organisms of both plant and animal origin. The plant component of the plankton is called phytoplankton and the animal component is called as zooplankton. A third group can absorb dissolved organic matter called as saproplankton. The majority of

phytoplankton belongs to Chlorophyceae, Cyanophyceae and Bacillariophyceae. Their unique ability to fix inorganic carbon to build up organic matter through primary production makes them imperative component of the food chain in marine ecosystem.

TROPHIC LEVELS OF THE FOOD CHAIN

All organisms in an ecosystem can be placed in trophic levels depending on what energy source they rely upon and how they provide energy for other organisms in the food chain. With the exception of life near hydrothermal vents in the deep ocean, life is always dependent directly or indirectly on the energy from the sun. In every ecosystem, there is an organism at the lowest level that converts energy from the sun into useable energy for other organisms. For example, phytoplanktons are photosynthesizers that provide energy for a vast number of primary consumers, which in turn provide energy for secondary consumers and decomposers. Biologists study, how energy is used in the food chain, known as the economy of energy.

COMPONENTS OF THE MARINE ECOSYSTEM

There are four components in every ecosystem: the abiotic environment (e.g. geology or geography), producers (e.g. phytoplankton), consumers (e.g. zooplankton and shrimp) and decomposers (e.g. bacteria). In marine ecosystem, (Figure 1.2) trophic levels begin with phytoplankton, a primary producer capable of transforming inorganic carbon into protoplasm. Zooplankton is the second level component because they consume phytoplankton and are a source of energy for crustaceans at the third level. The fourth level is fish that eat crustaceans and the fifth is seals and other animals that eat fish. The more trophic levels present, the less energy is conserved at higher trophic levels.

With a few exceptions, every species fits into the ecosystem as something consumed and something that consumes other organisms. Many preys are eaten by more than a single predator and most predators have diversified to eat more than one type of prey. The amount of biodiversity in an ecosystem is directly related to its degree of stability. When organisms eat a variety of foods, the loss of one type of prey is not as devastating to the overall ecosystem. Thus, it causes transfer of energy through different trophic levels of an ecosystem.

Figure 1.2 Food web showing energy transfer at different trophic levels in marine ecosystem

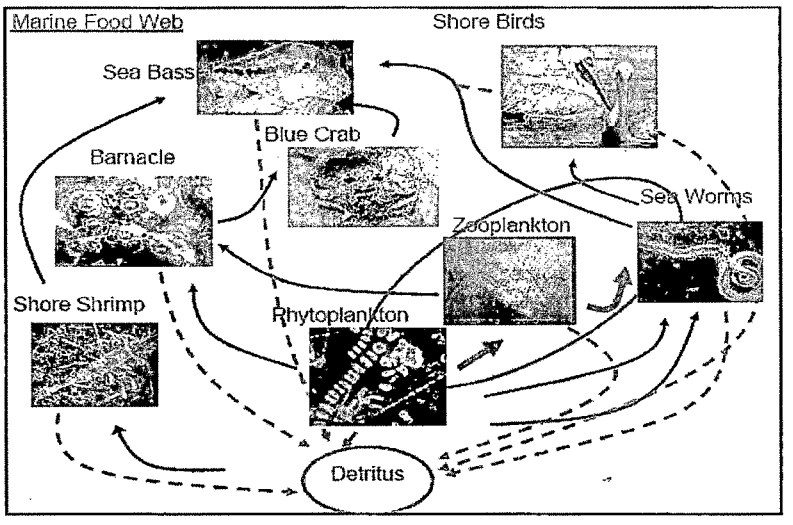
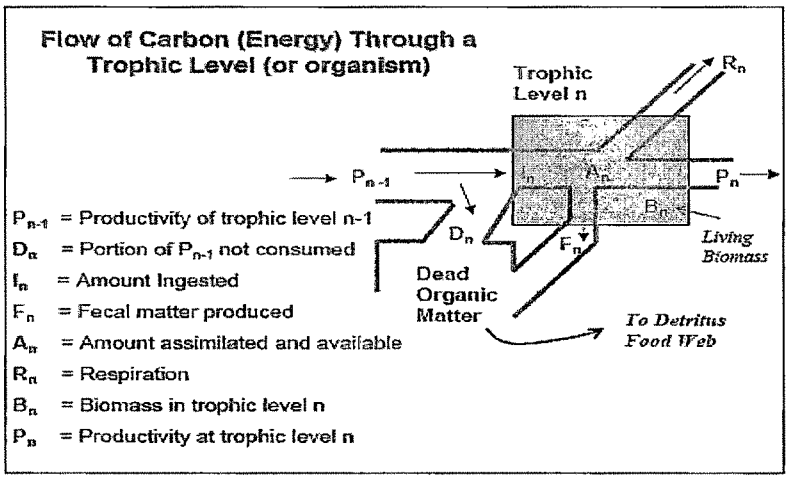


Figure 1.3 Flow of energy through different trophic level (organism) in marine ecosystem



The trophic levels are the levels within the food chain in which energy is transformed (Figure1.3). According to basic principles of thermodynamics, some energy is always lost to the environment any time an organism at one trophic level uses the energy from the trophic level below. For example, the energy gained by animals that eat phytoplankton is less than the amount of energy initially available. Every trophic level loses energy, so trophic levels are often illustrated as a triangle with primary producers forming the base. The zooplankton (primary consumers) plays an important role as energy source in the

marine ecosystem. The global survey showed that an ecosystem with naturally low diversity and productivity of zooplankton population, more frequent "collapses" (operationally defined as strong reductions in fishery yield) was noted. This further influences the entire marine biodiversity. Hence, taking in consideration the above aspects, the study was concentrated more towards the marine fauna.

GENERAL FAUNAL CLASSIFICATION IN MARINE ENVIRONMENT

The marine fauna is generally classified into two types, Pelagic and Benthic i.e.

Pelagic (living in the water column)

1. Plankton: float or drift in surface waters
2. Nekton: swimmers; move laterally and vertically

Benthic (living on the sea bottom)

1. Epifauna: at the surface
2. Mobile: crawl or swim
3. Sessile: attached
4. Infauna: within the sediment – burrowers

CLASSIFICATION

Irrespective of the fact, whether plankton belongs to plant (Phytoplnkton) or animal (Zooplankton) origin, it is divided into two groups.

1. Euplankton: All true plankton
2. Pseudoplankton: Dead plankton and nonliving debris

ZOOPLANKTON

In an aquatic ecosystem zooplankton form an important link in the food chain from primary to tertiary level leading to the production of fishery. It has been well established that potentials of pelagic fish's *viz.* fin fishes, crustaceans, mollusks and marine mammals either directly or indirectly depend on zooplankton. By virtue of sheer abundance and intermediatary role between phytoplankton and fish, they are considered as the chief index of utilization of aquatic biotope at the secondary trophic level. The herbivorous zooplanktons are efficient grazers of the phytoplankton and have been referred to as living machines transforming plant material into animal tissue. Hence, they play an important role

as the intermediaries for nutrients/energy transfer between primary and tertiary trophic levels. Due to their large density, shorter life span, drifting nature, high group/species diversity and different tolerance to the stress, they are being used as the indicator organisms for the physical, chemical and biological processes in the aquatic ecosystem (Gajbhiye, 2002).

Zooplanktons are characterized by their faunal diversity compared to phytoplankton and include arrays of animal organisms, varying in size from the microscopic protozoans of a few microns to some jellyfish with tentacles of several meters. No single system of classification has been adopted universally. They have been classified into several groups by size (Cushing *et al.*, 1958)

1. Ultraplankton : <05µm
2. Nanoplankton : 05 – 60µm
3. Microplankton : 01 – 500µm
4. Mesoplankton : 0.5 – 1.0mm
5. Macroplankton : 01 – 10mm
6. Megaplankton : 10mm

The larger organisms (20 – 100mm) are called micronekton. Depending upon the size (Raymont, 1983), the zooplankton are divided into megaplankton, macroplankton, mesoplankton, microplankton and nanoplankton.

ECOLOGICAL CLASSIFICATION;

I) On the basis of their habitat:

1. Marine plankton: Haliplankton
2. Brakishwater plankton: Hypalmyroplankton
3. Freshwater plankton: Limnoplankton.

II) On the basis of length of planktonic life:

1. Holoplankton: (Permanent plankton; holo - entirely): Those living as plankton during their entire life e.g. Copepods, Chaetognaths etc.
2. Meroplankton: (Temporary plankton; meros - mixed): Those living as plankton during only a part of their life e.g. Eggs and larval stages of fishes.

III) On the Basis of depth distribution:

1. Pleuston: Living at the surface of the sea, part of whose bodies project in to the air e.g. *Physalia* and *Velella*
2. Neuston: Living in the uppermost part (few to 10mm) of the surface layer
3. Epipelagic: Living between 0-200m
4. Mesopelagic: Living between about 200 and 1000 m in daytime
5. Bathypelagic: Living below 1000m

IV) On the basis of food habit:

1. Herbivores: Those zooplankton feed on phytoplankton are called herbivores. e.g. Copepods, shrimps
2. Carnivores: Those zooplankton feed on other small zooplankton are called as Carnivores. e.g. Chaetognaths, Ctenophores etc.
3. Omnivores: Those zooplankton feed both on phytoplankton and zooplankton are called omnivores.

ECOLOGICAL SIGINIFICANCE OF ZOOPLANKTON

VERTICAL MIGRATION

Many groups of zooplankton such as Copepods, Amphipods, Euphausiids and Chaetognaths are known to make diurnal vertical migration. These migrations may extend to depth of several hundred meters and in some instances, even to 1000m or more, in which they undertake daily journey from the bottom to the surface at the approach of darkness and return to deeper waters at or before daybreak. Although light intensity is considered the prime factor for this phenomenon, other factors such as temperature, gravity pressure and predators are also known to influence this phenomenon.

BIOLUMINESCENT ZOOPLANKTON

A few species of Medusae, Ctenophores, Siphonophores, Ostracods and Euphausiids are bioluminescent and are capable of emitting light. The light so produced acts as a warning signal to the predators of these organisms and assists them in locating the predators.

ADAPTATION OF ZOOPLANKTON

In case of many of the zooplankters, which are incapable of active movement, buoyancy is achieved by means of morphological adaptations, which increase frictional resistance. The

increase in surface body area due to feather like projection or development of long spines or extreme flattening of the body helps the zooplanktons to float passively. In the case of medusae, siphonophores, ctenophores, tunicates, fish larvae etc. flotation is mainly archived by the inclusion of more fluids in the body, which reduces the specific gravity of a given volume of water. The buoyancy of other siphonophores, such as *Physalia, Velella* and *Porpita,* is due to the presence of air-filled organs, *viz.* pneumatophores. The foamy mucous substance secreted by it facilitates flotation of the planktonic gastropod *Janthina.* The shell of *Janthina* and *Petropod* is very delicate and frigate and does not allow the animals to sink.

OOZE FORMATION

The shell or tests of protist plankton such a foraminifera, radiolarians; and gastropod molluscs *viz. Pteropods,* contribute to the formation of "globigerina ooze", radiolarian ooze, occurring over wide areas of the sea floor, might will be a resource material for thermal insulators and chromatographic columns.

ZOOPLANKTON AS INDICATORS

Many species of zooplankton are also known to be indicators of the specific water masses in which they are abundant. The arrow worms (Chaetognatha) in particular *Sagitta elegans* and *S. setosa,* are known to, indicate the presence of mixed and unmixed waters in the North Sea and the English Channel respectively. The appearance as *S. elegans* in the North Sea is always associated with the inflow of Atlantic water, resulting in good fishery. On the other hand, when *S. setoss* is present in the channel water, young fish are scarce. The association of Copepods, in particular *Calanus* species, with rich herring shoals is also worth mentioning. The abundance of krills of the species *Euphausia superba* helps fisher men in locating baleen whales, seals and squids. This relationship is a direct one as krills constitute the basic food of baleen whales (Santhanam and Srinivasan, 1994).

ECONOMIC IMPORTANCE OF ZOOPLANKTON

In Arctic and Antarctic area where the *Euphausiid* krill predominate, fishing of krill is a profitable venture. It has been suggested that krill may one day rival soybeans as a source of protein. The annual production of krill has been estimated at 200 million tons, which is more thane 2 times the world fish catch. However, the annual krill catch is presently only 20,000 tons. Hence there is a good scope for expanding fishing operation, particularly in

the vicinity of krill rich grounds. Krill could be a good source for the large scale preparation of fish protein concentration (FPC), an easily digestible direct human food. Further more, it is also incorporated in poultry and other livestock feed. Certain species of mysids are collected for food in the East Indies. Similarly, deep water Copepods, namely *Euchaeta nonvegeca* is a delicacy which one-day might support the fisheries for luxury markets. Although the collection of plankton as human food is not going to be a profitable venture except for Arctic and Antarctic krill, plankton from other latitude even though of less magnitude, is a potential resource for pharmaceutical. Most of the commercially important pelagic fishes feed on zooplankton, hence, the study on prevalence and distribution of zooplankton is necessary in production potential of a given ecosystem. Investigations on zooplankton have been confined mainly to taxonomy, zoogeography, distribution pattern, community structure and trophic relationships. However, efforts are underway to integrate studies to biological and physical phenomena in the ocean. All these factors together influence the ecology and biodiversity of marine ecosystem.

RATIONALE FOR THE CURRENT STUDY

Internationally, numerous seminars and workshops have been conducted serving the importance of conserving marine biodiversity. Worldwide, Marine habitats from the intertidal zone out to the continental self break are estimated to provide over US$ 14 trillion worth of ecosystem goods (e.g. food and raw materials) and services (e.g. disturbance regulation and nutrient cycling) per year or 43 % of the global total (Costanza *et al.,* 1997). Coastal environmental plays a vital role in nation's economy by virtue of the resources, productive habitats and rich biodiversity.

India is no exception, with a coastline of about 7,500 km, including Lakshadweep coast extending up to 132 km and Andaman and Nicobar Islands have a coastline of about 1,900 km. The coastal zone of India is endowed with a very wide range of coastal ecosystem like Mangroves, coral reefs, sea grasses, salt marshes, sand dunes, estuaries, and lagoons etc, which are characterized by distinct biotic and abiotic processes. The Indian coasts also have a diverse coastal flora and fauna. Some of them are endemic to specific areas. Moreover, in recent years, owing to mushrooming of the human population, urbanization and accelerated developmental activities put tremendous anthropogenic pressure on the fragile coastal environments of our country. These marked alterations in the coastal and marine environments have led to deteriorations in the water quality and has been

detrimental to the species diversity from the lowest trophic level; plankton to the highest forms of marine flora and fauna. These conditions were more prominent in highly industrialized state like Gujarat where coastal ecosystem is exceedingly perturbed, particularly one resulting from human activities.

The entire state of Gujarat is classified into five regions *viz* the Rann of Kutch, Gulf of Kutch, Gulf of Cambay, Saurashtra coast and the south Gujarat coast. The Kutch region forms the northwestern part of Gujarat state, the northern limit marked by the international border with Pakistan. To the south and west of Kutch lies the Arabian Sea, while in the east, it is bound by the Rann of Kutch. Lamentably, the coastal zones of Gujarat are subjected to dual act of pollution and over exploitation of its resources in the past few decades. Major rivers of Gujarat e.g. Kolak, Damanganga, Amba, Tapi and Narmada carries heavy loads of waste discharges responsible to contaminate the estuaries and coastal waters of Gujarat (Zingade and Desai, 1987).

Amongst the entire coastal regions of Gujarat, Saurashtra coast is one, which has attracted very little attention from the Marine environmentalist regardless of its rich biodiversity. However, in the past few years, the three flourishing cities under the Saurashtra belt *viz* Alang, Diu and Veraval; have gained much scientific attention for several legitimate reasons. These three cities, due to the rapid industrialization and recreational activities are susceptible at all levels, which are manifested to its ecological unit especially Marine ecosystem. The Marine diversity loss at all the three places largely remained unquantified, as very few composite works have been undertaken. Among all the three sites, Alang is considered as highly polluted, whereas Veraval and Diu were manifested as moderate to least polluted zones of the state. Several human interventions/activities along the coastal belt of these three places *viz* Alang, Diu and Veraval have remarkable affect on the biodiversity of the marine ecology. The foremost sources of pollution in Veraval are through the dumping of waste and fish trash from the nearby fishing industries. Ballast and hydrocarbon waste, spilling of oil and cargo chemicals from the shipping industries are the major basis of contamination of the coastal waters in Alang. Diu, is not excluded, development of tourisms in the Island at an alarming rate are also answerable for coastal pollution in the state of Gujarat. The expulsion and disposal of untreated domestic wastes from the nearby Hotels, coolant waters are all dumped into the Sea water prior to suitable treatments. This has resulted in severe deterioration of the water quality. An expected

consequence of this degradation would be the change in the biodiversity of Marine ecosystem.

The present study therefore, was undertaken to understand the existing status of the richness, diversity and population dynamics of plankton at three sites with diverse environmental conditions *viz* Alang, Diu and Veraval in the coast of Saurashtra. Spatial and temporal distributions of plankton species was also characterized and are compared with varying physicochemical parameters of the coastal waters. The distribution patterns were evaluated using multivariate ordinations techniques.

STUDY AREA

SAURASHTRA COASTLANDS

The coastland of the Saurashtra stands out as a distinct geographical region because of its geological structure and economic development. The coastline provides an interesting evolutionary model of a complex interplay of sea-level and tectonic changes during the Tertiary and Quaternary periods. Its geological and geomorphological attributes point to many significant facts which are not yet properly understood, and this coastline comprises a somewhat controversial geomorphic unit of the western India. Suarashtra coastline very clearly reveals a northward tilting of the peninsula. The northern coast of Suarashtra points to a submergence and the southwestern and southern coast typically shows uplift.

GEOGRAPHY

The coastline lies between the N latitudes 21° 1' 50" and 21° 50' and E Longitude 71° 43 and 72 °37 ' 30" E forms a portion of the survey of India Toposheets No 41/12, 15 and 16; 46C/ 1,2,3,4,5,6 and 7. The peninsula is surrounded by Gulf of Kutch in the north, Arabian in the south and Gulf of Khambatt in the east. The core portion of Saurashtra rises up to 300 ml above Sea level and is known as Jasden plateau. The southern hilly terrain of the Saurashtra is the conspicuous Gir highlands ranging in height from 100m to 480 m.

GEOLOGY AND TOPOGRAPHY

Geologically, the Saurashtra peninsula essentially forms a Deccan trap plateau, occupying two third of the total area. The trap rocks overlie the upper Mesozoic sediments which are exposed in the northern part of the peninsula and are in turn, fringed by the Tertiary and Quaternary sediments along the coastline.

Topographically, Saurashtra coastline is arc shaped coastal terrain comprising of a variety of physiographic features and is divisible longitudinally into following three zones on the basic land forms – a. Inner zone of Trappean hills and plateaus, b. Coastal plain and c. Shoreline.

All along the west and North West of the coastline, its interior flank is characterized by a rocky terrain made up of a plateau. The rocks are mainly basalt flows and dolerite dykes. The higher portion of this hilly terrain in the west forms a part of the eastern extension of the Gir range, which takes a turn to northeast on crossing the river Shetrunji. On going seaward, the rocky terrain passes into the coastal plain. These plains, characterized by an alluvial cum soil cover, show a variable serial extent for SW to NE. The actual shoreline of Saurashtra provide interesting coastal features comprising coastal dunes, mudflats, deltas, cliffs, rocky platforms and beaches.

DRAINAGE

Numerous rivers and streams originate in the Trappean hill ranges and meet the Gulf of Cambay or the Arabian Sea., after flowing across the coastal plains for distance varying between 20and 60km.

CLIMATE

The Tropic of Cancer passes through the state of Gujarat putting it in to the sub-tropical climatic zone. The Saurashtra coast is experiencing arid to semi arid type of climatic conditions. The winter season is pleasant, extending from November to March, the average minimum temperature during the winter being about 18° C. The summer months are April, May and June. With the vent of summer by the end of March the temperature rises, the mean maximum temperature during summer being around 38° C. Owing to cool sea breeze, in the coastal belt, heat is less but still oppressive. By the end of June, the area receives southeast monsoon rains, which continues till the end of September. During this period, it is rarely warm and humid. The relative humidity is generally about 80% during the SW monsoon period, otherwise remains drier during the rest of the year. Southwest winds blow with more velocity than northeast; the latter prevails only during the winter and does not cause much rain. The rainfall in Saurashtra varies between 300mm and 800mm; the highest being received by the Gir highlands. The mean vector of the southeast wind direction is approximately between N 30° – 60° E.

VEGETATION ALONG THE SHORELINE

The present day vegetation along the estuarine mudflats is characterized by mangroves *Avicennia marina* and *Saliconia brachiata*. On the raised mudflats (high marshes) grow *Sueda nudiflora*. *Cressa cretica* is seen near the salt pans. Sandy beaches are dominated by *Ipomoea pescaprare* and *Sesuvium portulaca*, though sporadically *Aeluropus lacopoidis, Launacas arementosa* and *Borreria articularis* are also seen. The common plants of the rocky platforms are *Lindenbergia indica, Kickxia ramosissima* and Portulaca *quadrifida*.s The stabilized dunes support vegetation comprising *Berreria articulate, Echinops echinatus, Portulaca angustifolia, Ipomea pes-caprae, Vernonia cinereae, Trichodesma indicum* and *Corcnorus dispressas*.

VEGETATION ALONG THE COASTAL PLAIN

The coastline plain vegetation mainly comprises of shrubs, under shrubs, herbs and climbers growing on the shrubs. The most common shrubs are *Euphorbia sp*. Bigger is restricted along the banks of the streams and river and around the villages. Trees of *Acacia senegal, Ficus bengalensis, Ficus religiosus, Azadirch ra indica* and *Prospis spicigera* are observed.

FAUNA

The wildlife of the southeastern Saurashtra consists mainly of deer, Fox, Wild cat and Wolf. Reptiles of different species are also common, the most deadly snakes being cobra, several birds including peacock, wild ducks, strokes, cranes and pelicans are seen.

INTENSIVE STUDY AREA

The entire Intertidal stretch of the Saurashtra coast was traced through reconnaissance survey to select the suitable sampling stations. The study area was selected considering the tidal influence, in manner such, that one zone is highly polluted, second moderately polluted, and the third with least pollution being considered having pristine quality of water. Later however, it was realized that no zones are totally free of contamination. The location of the three sampling stations *viz.* Diu, Veraval and Alang are presented in the (Figure 1.4).

Initially monthly sampling was decided from the three selected sites. Later on, it was

amended for seasonal collections. Moreover, it was not possible to visit all the three locations for sampling every month of year due to inconvenient approaches.

STATION 1: DIU (Position: N 20° 42' 260″ E 70° 58' 683″)

It is an Island lying off the south coast of Gujarat along the kathiawara peninsula. Blessed with scenic beauty, it became the recreational spot but the years of recreational activities have brought widespread damage to the ecosystem. As treated or partially treated sewage waste and other solid fritters like plastics, canes etc were directly dumped into the sea from the nearby hotels and residential areas (Gujarat maritime board). The land used pattern and on site picture of the Diu are shown in figure 1.5, 1.8 respectively.

STATION 2: VERAVAL (Position: N 21° 52' 945″ E 70° 21' 231″)

It is located in the open coast of Arabian Sea. Veraval is an important intermediate fair whether port. Fishing is the main occupation of the local inhabitants using mechanized boats and vessels (Figure 1.8). Operation of these vessels generates huge amount of pollutants and domestic waste. In addition to this, effluents, mainly organic waste generated from the 42 fish processing industries located in the nearby GIDC, are also discharged into Sea (Gujarat maritime board). The land used pattern of the Veraval is shown in (Figure 1.6).

STATION 3: ALANG-SOSIYO (Position: N 21° 34' 308″ and E 72° 09' 991″)

It is situated on the Western coast of Gulf of Cambay. Alang-Sosiyo is the second largest ship-scrapping yard in the world established in 1982. The beach is in fact one of the longest continental shelves with the second highest tidal port in the world a very rare occurrence, which makes Alang a geographically natural tidal dry port and ideal for the ship breaking industry. The land used pattern of the Alang is shown in figure 1.7 and the site photograph is given in figure 1.8.

GEOLOGY AND GEOMORPHOLOGIC DETAILS OF DIU, VERAVAL AND ALANG

DIU

Diu is island situated slightly off the coast of Kathiawar near the Port of Veraval in Gujarat with a coastal length of 21 km which is at a distance of about 768 km from Daman, the Capital of the newly formed Union Territory of Daman and Diu. Junagadh and Amreli

District in North and the Arabian Sea bounds Diu from the three sides. It is connected by two bridges with the mainland. The district of Diu is situated between the parallels 20°-44'-34" and 20°-42'-00" of latitude north and between the meridians 71°-00'-24" and 70°-52'-26" of longitude east of Greenwich. Its length from the extreme north and south, measures 4.6 km and width from east to west measures 13.8 km. The altitude is 6 meters above sea level. The topography is generally plain. The hillocks attain maximum height of 30 meters. Geologically and geomorphologic features of Diu shows that the beaches in the Diu are gentle low angle (~ 3-4°). This is composed of mainly medium coarse to gravelly shell limestone. The sandy beach is backed by about 3 m high beach ridge and backshore dunes. The Diu coast have high cliffs with medium grained, thinly laminated and highly bioperturbated limestone. Interestingly, there are miliolite limestone ridges or mounds that separate the Diu Island from Saurashtra mainland.

VERAVAL

The Veraval is fair weathered port. The district of Veraval is situated between the parallels 20°-54' of latitude north and the meridians 70°-22' of longitude in the south west coast of Saurashtra and on the west coast of India. It has an average elevation of 0 meters above sea level. The coastal region is having higher rainfall, greater productivity and high density of population. The northern part of Veraval is occupied by the saline wasteland extending on the both sides river Badar. Veraval also enjoyes a long coastline, lined with beaches. Beaches extend uninterrupted almost throughout the veraval coast. Only a small portion of the beach has been commercialised and majority of the beach is still virgin. The city is known as an important coastal town's port. The port is generally engaged in fishing activities. Commercial operations are extremely limited. East of Veraval has been identified as for development for deep water port. Geomorphologically, Veraval exhibits distinct coastlines, with prominent occurrences of impressive coastal cliffs, shore platforms and sea stacks and linear sandy beaches. There are ephemeral streams entering the entire stretch of Veraval–Jafrabad segment that usually bring water and sediments in the monsoon season. Number of fossil dunes dots the Veraval coast. Geologically, Veraval shore platforms are made of recrystallized limestones that are mainly exposed during the low tides.

ALANG

Alang is a modern day wonder of Gujarat. Alang - Sosiyo is located on the western coast

of Gulf of Cambay, in Bhavnagar stretch, located in western part of India. Alang has a very high tidal range (~ 13m) in the world, gentle sloping and firm and hard rocky bottom. Ships can be floated to the work place. The beach is in fact one of the longest continental shelf's with the second highest tide port in the world. This makes it geographically natural dry tidal port. It is considered as India's largest ship-breaking yard. Here large ships from America, Europe, Asia ranging from super tankers, container ships, warships and other vessels are dismantled and scrapped. It is a fantastic spectacle. The reason behind the selection of this site was the nature of its tide, suitable for such maritime activities and the proximity of industrial zones that could utilize its metal and other scrap.

Geologically and geomorphologically, the complete stretch consists of low and high marshes, mangrove swamps and tidal inlets, point bars and islands, off shore bars and marine terraces. The sediments are mixtures of clay and slits with a sprinkle of sandy gravel. From the high water line (inner periphery) for nearly 500 to 800m, the sediments are predominantly clay and slit, with frequent layers of well rounded medium to fine grained sand. Beyond 800m towards the sea they are predominantly clay and slit. The banks of the creek on the entire stretch are dotted with mangroves on both the sides. All along the coastal segments, the mudflats are dissected by numerous tidal channels, which mark the mouths of the various rivers that flow into the Gulf. An extensive off-shore bar is seen developed, about one and half kilometers away from the main coast. This bar is obviously a result of the long-shore drift and deposition of the Gulf sediments. From the point of view of landforms, this segment shows several interesting fore-shores and back shores features, though the bar line dividing the two is not well defined. The land form features of the shoreline shows, intertidal platforms which are mainly the product of wave action. It is seen as gently seaward sloping rocky plane excavated out of mainly laterites, Gaj and Lakhanka rocks. The platform all along its length is seen covered by mud throughout the year, except during monsoon and immediately after it for a month or so, during which period, the muds are washed in to the sea. In Alang occasional well developed dunes are recorded. The sand dunes consists of arenaceous material – made up of quartz, agate, chalcedony and rock fragments.

CLIMATIC CONDITIONS

The climate of Diu is normally pleasant throughout the year. The Monsoon season lasts from June to September with maximum rainfall being 25" or 63.5cm. The mean maximum

temperature does not exceed 38° C and the minimum does not fall below 15° C during summer. In winter, it ranges from 20° to 25° C.

In Veraval the climate is quiet harsh with summer being warm and dry and temperature reaching in excess of 36°C. The winter in turn are quiet pleasant with the average low temperature dropping up to 11°C. The Veraval records an average rainfall of 18". The best time to visit the city is during the months of October to March.

Alang have dry tropical monsoon climate with an average annual rainfall of about 800 mm. The monsoon commences on June or July and ends in September, but the rainfall is erratic in occurrence, duration, and intensity. The winters are generally cool and dry, with minimum temperatures around 10° C. The pre-monsoon period in March-June is very hot, with temperatures reaching 45°C.

OBJECTIVES

The Saurashtra coast is considered to be important from economic and livelihood perspective. The scrutiny of literature showed that previous studies on the Saurashtra coast were concentrated more on extensive taxonomic profiles of the live corals, their contribution and significance to the ecosystem. The other studies includes the socio – economic aspects of the earth quake prone areas of the Saurashtra belt (Ragunathan *et al.,* 2004) and few intermittent studies on faunal compositions of the North and South coastal regions of the Saurashtra. Nevertheless, the Saurashtra coast is constantly under relentless stress conditions, which bring variations in its hydrological features that include inconsistency in the physical, chemical and biological characteristic that facilitate the phytoplankton population for variability in its production and standing crop, that is responsible for 90% of productivity in the Ocean. This randomness leads, to uneven scattering thus brining temporal alterations within the community. This eventually have an effect on zooplankton composition of the next trophic level in the food chain. Therefore, **the first objective was set to understand the factors that overtly influence these fluctuations in the primary producers (phytoplankton) – the dissolved nutrients** (Chapter 3).

Plankton community is remarkably diverse despite its continued exposure to subjective variations in the coastal ecosystem due to many unprecedented reasons. In spite of the

variations in the marine environment, many of the species have the ability to abide the gradients in environmental properties, which may predispose them to being able to survive in an array of oceanographic conditions and thus brining alterations in the floral and faunal community composition. These compositional variations are not only restricted to different trophic levels in the food chain but also to diverse taxonomic levels in the plankton community. However, very few composite works has been undertaken regarding the alterations in community at the taxonomic level, and understanding its diversity and ecology of the planktonic fauna of the Saurashtra coast. In view of the above mentioned approach, the second **objective therefore, was to characterize the ordination of zooplankton community data, to understand the trends in the community structure of marine zooplankton at Saurashtra** (Chapter 4). The zooplankton (primary consumer) being the second important member of the food chain, the faunal components were studied. The overall annual variations in physicochemical properties were also analysed, as the plankton community may be sensitive to the seasonal variations occurring in the physicochemical properties of water. Thus, the knowledge of the community structure of plankton at the three places of the Saurashtra coast and its relationship to the prevailing environment and further analyzing its interrelationship with the phytoplankton population at all the three stations was essential to understand the complete state of the ecological unit.

Ecological theory also suggests that community structure determines how ecosystems respond to perturbation or interventions of anthropogens. Thus, predicting the dynamics of ecological systems following perturbation is another goal of ecology. The Saurashtra coast known for its rich biodiversity was subjected to unprecedented commercial exploitation, one resulting from human activities. This results in high level of anthropogenic compounds entering into the Marine waters from many defined and amorphous sources. This causes direct affect on the plankton diversity in respond to perturbations of the given area. Thus, the **final objective of the study was to assess the impact of petroleum hydrocarbon on the community structure of plankton in the coastal waters of Saurashtra** (Chapter 5).

Figure 1.4. Location map of the sampling stations

★ Diu

★ Veraval

★ Alang

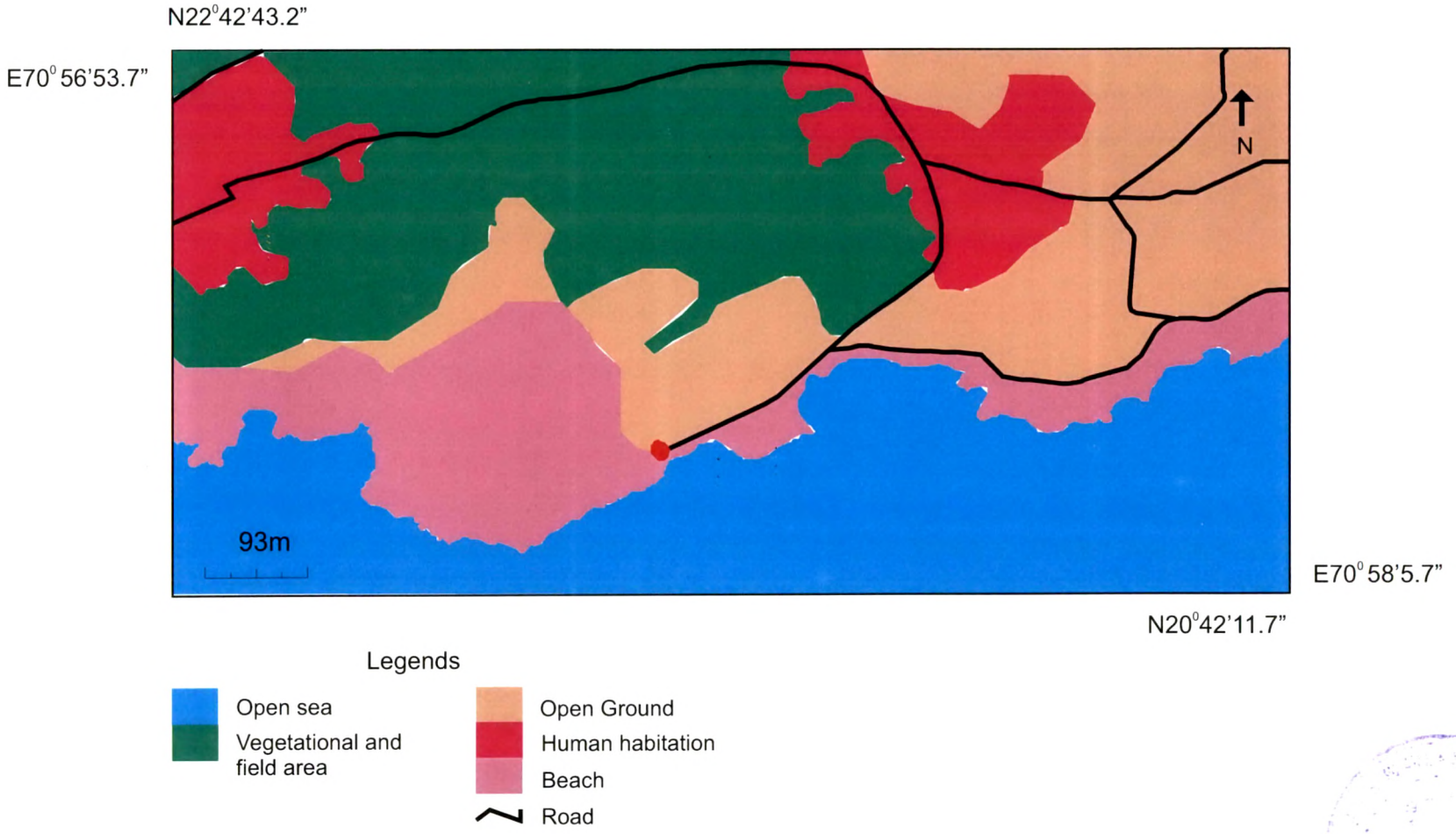


Figure 1.5 Land use pattern of study site - Diu

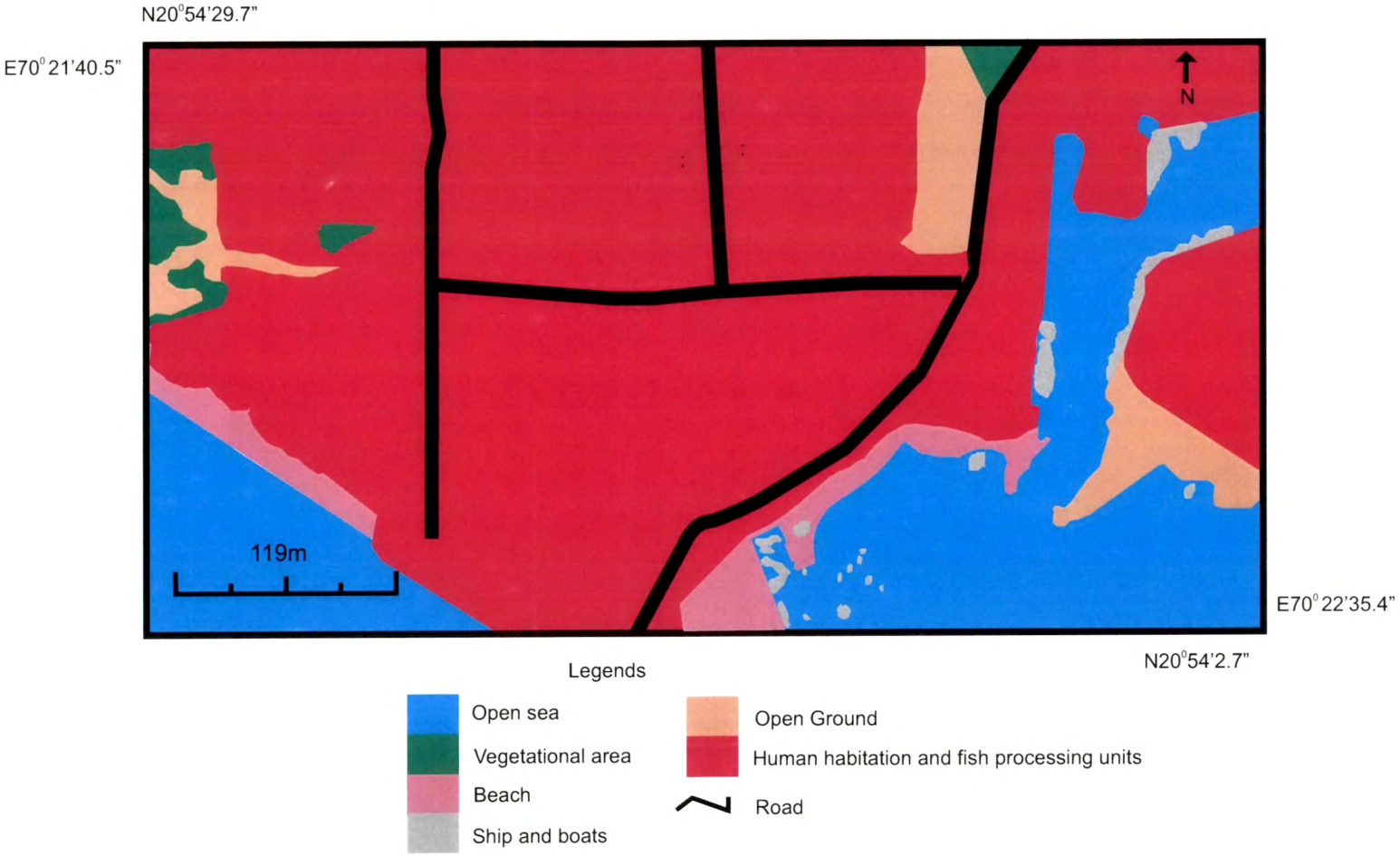


Figure 1.6 Land use pattern of study site - Veraval

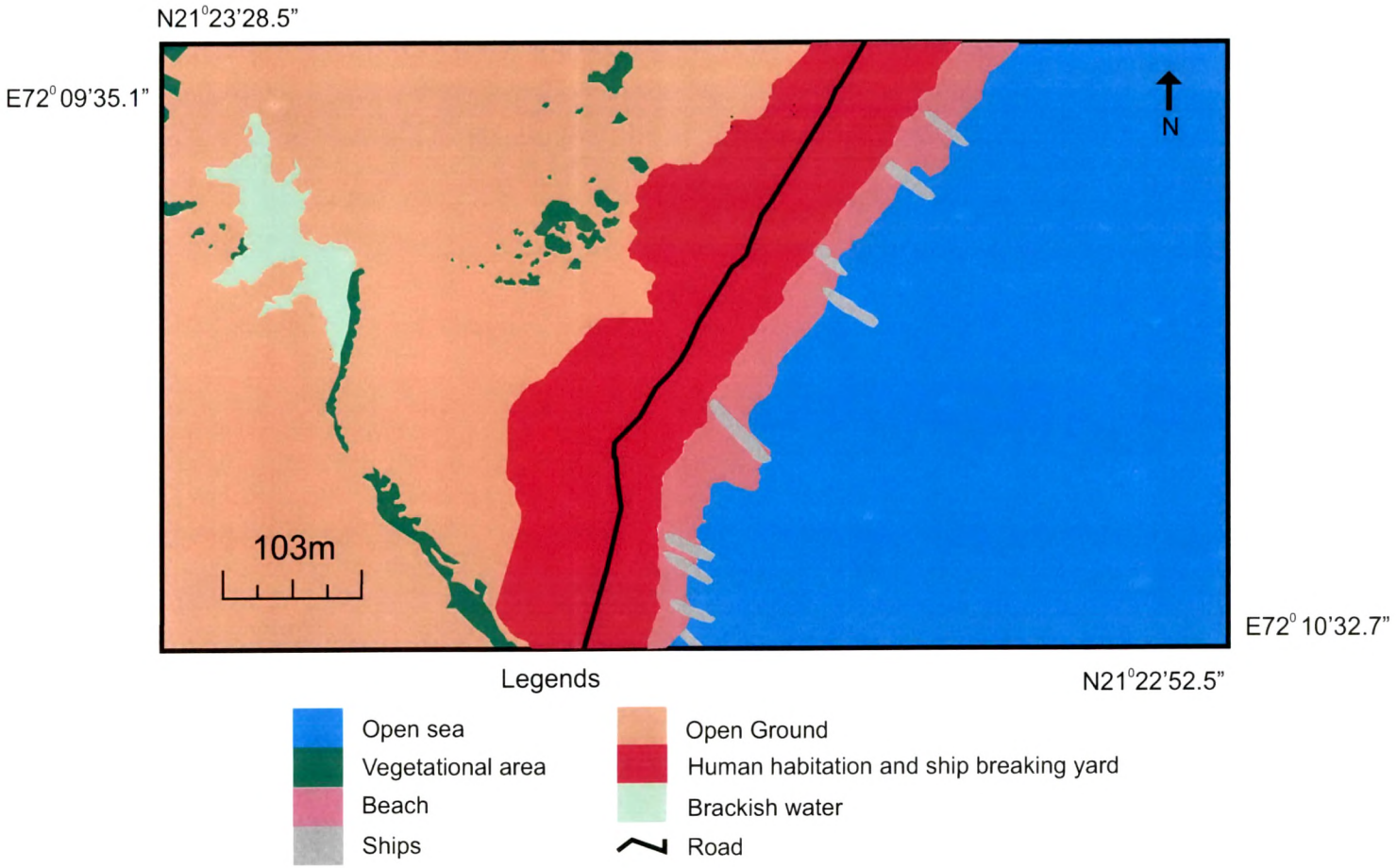
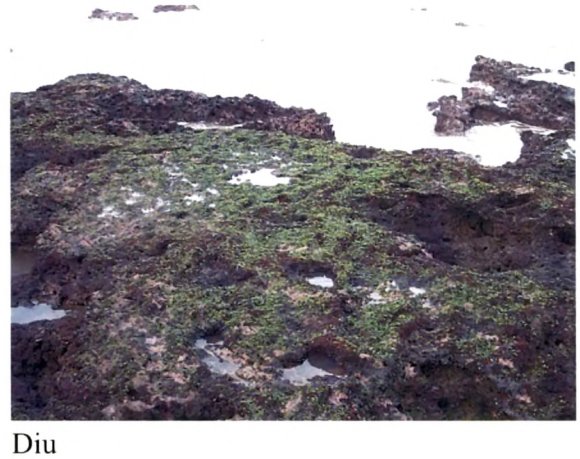


Figure 1.7 Land use Pattern of Study Site - Alang

Alang

Alang

Diu



Diu

Veraval

Veraval

Figure 1.8 Study sites at Diu,Veraval and Alang