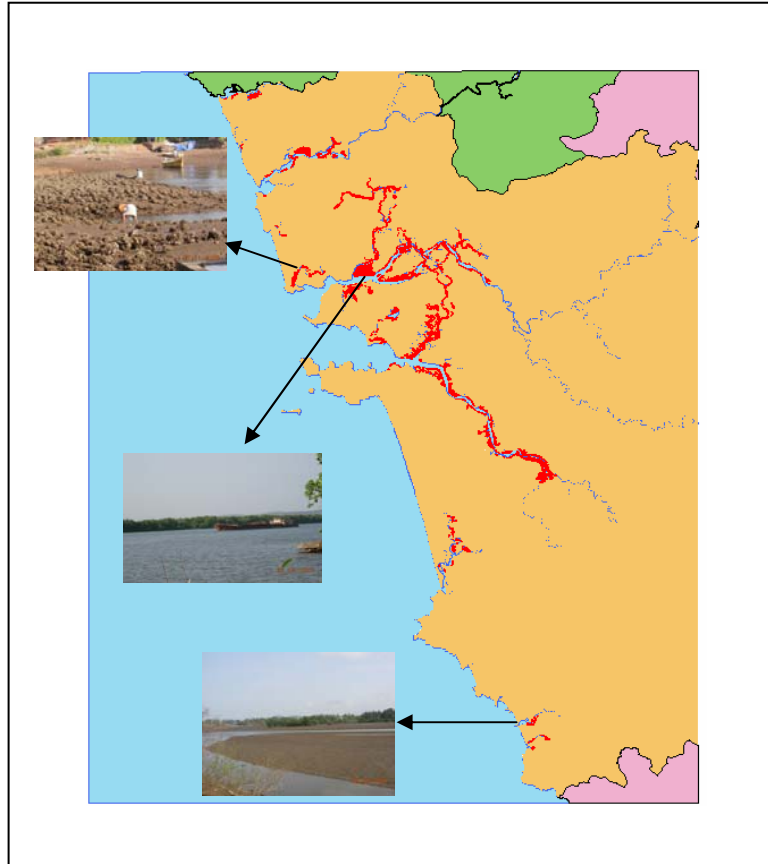


# ENVIRONMENTAL STUDIES ON MANGROVE COVER CHANGES IN GOA, AND ITS RESIDENT CRASSOSTREA POPULATION



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**ENVIRONMENTAL STUDIES ON MANGROVE  
COVER CHANGES IN GOA, AND ITS  
RESIDENT CRASSOSTREA POPULATION**

**Thesis submitted to Goa University  
for the degree of  
Doctor of Philosophy  
In  
Marine Science**

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**August 2008**

*..... DEDICATED  
TO THE MEMORY OF  
MY BELOVED FATHER  
LATE MOHAMED HAMOUD NAGI*

## **CERTIFICATE**

This is to certify that the thesis entitled “Environmental Studies on Mangrove Cover Changes in Goa, And Its Resident Crassostrea Population”, submitted by Mr. Hisham Mohamed Hamoud Nagi, for the award of the degree of Doctor of Philosophy in Marine Science is based on original studies carried out by him under my supervision.

The thesis or any part therefore has not been previously submitted for any degree or diploma in any universities or institutions.

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## *STATEMENT*

As required under the University Ordinance 0.19.8 (vi), I state that the present thesis entitled “**Environmental Studies on Mangrove Cover Changes in Goa, And Its Resident Crassostrea Population**” is my original contribution and the same has not been submitted on any previous occasion. For the best of my knowledge, the present work is the first comprehensive work of its kind from the area mentioned.

The literature related to the problems analyzed and investigated has been appropriately cited. Due acknowledgements has been made wherever facilities and suggestions has been availed of.

Place: Goa, India.

Date:

**(Candidate)**

**Hisham Mohamed H. Nagi**

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## **LIST OF ABBREVIATIONS**

- ANOVA: Analysis of Variance.
- CI: Condition Index.
- CRZ: Coastal Regulation Zone.
- DO: Dissolved Oxygen.
- EIA: Environmental Impact Assessment.
- ESMH: Ecological Sensitive Marine Habitat.
- FCC: False Color Composite.
- GIS: Geographical Information System.
- GPS: Global Positioning System.
- HTL: High Tide Line.
- IRS: Indian Remote Sensing.
- LISS: Linear Imaging Self Scanner.
- LTL: Low Tide Line.
- MoEF: Ministry of Environment and Forests.
- MSS: Multi-Spectral scanner.
- NATCOM: National Mangrove Committee.
- ND: Not Detected.
- NDZ: No Development Zone.
- NGOs: Non Governmental Organizations.
- NIO: National Institute of Oceanography.
- NIR: Near Infra Red.
- NIR: Near Infra-Red.
- NRSA: National Remote Sensing Agency.
- PE: Percentage Edibility.
- POC: Particulate Organic Carbon.
- RS: Remote Sensing.
- SOI: Survey of India.
- TD: Transformed Divergence.
- TM: Thematic Map.

### GENERAL INTRODUCTION

#### 1.1. The Coastal Zone:

There are several definitions for the coastal zones. However, the following is common and accepted by world scientific communities (Beer, 1997):

*“The land and waters extending inland for 1 km from high water mark on the foreshore and extending seaward to the 30 m depth contour line, and also including the water, beds, and banks of all rivers, estuaries, inlets, creeks, bays, or lakes subject to the ebb and flow of the tide”*

Accordingly, coastal zone extends inland as far as the tide affects the shore. Estuarine and deltaic river mouths can be thought of as comprising coastal waters. The line, which separates the marine waters from the terrestrial domain, is called the shoreline, which constitutes a very marked physical barrier for living organisms on the planet earth (Barnabé and Barnabé-Quet, 2000).

Most of the coastal regions in the world are characterized by ecological sensitive fragile ecosystems, essentially because they represent the interface between the land and the sea. These coastal areas are being subjected to high human pressures, as mass movement of people has been

observed from the hinterlands towards the coastal areas during the late 20<sup>th</sup> and 21<sup>st</sup> centuries. Today, about 40% of the world's population residing within 100 km of the coastline (Noronha, 2003).

Lately, the coastal zone has gained a high-priority interest to people, commerce, the defense, and a variety of industries. As a result, the low lying regions along the maritime jurisdiction have been subjected to intensive anthropogenic pressures such as urbanization, industrial and agricultural pollution, recreation and tourism, overexploitation of natural resources, waste disposal, shipping, fishery industries, aquaculture, mining, oil spills, etc. These unplanned activities have resulted in the reclamation and deterioration of marine wetland habitats to a great extent, all over the world, and particularly from the developing countries from the tropics.

The coastal zone under tidal regime, being productive, sustains a large part of the world's living marine resources, and represents the highest biological diversity (Clark, 1998; Dobson and Frid, 1998). It comprises variety of habitats including mangroves, salt marshes, seagrass meadows, seaweed systems, coral reefs, beaches (rocky, sandy, muddy), sand dunes, lagoons and estuarine systems of immense ecological and socioeconomic values. These habitats serve as nursery grounds; provide breeding shelters and feeding places and nurture of the young individuals of marine as well as terrestrial species.

## 1.2. Estuaries:

Estuaries have been variously defined by geologists, biologists, hydrologists and geographers. Thus, there is no one set of definitions that has been adopted by all disciplines (Blaber, 2000). However, definition coined by Day (1981) is widely accepted by biologists, which reads as:

*“An estuary is a partially enclosed coastal body of water is either permanently or periodically open to the sea, and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage”*

Tropical estuaries grade into subtropical systems beyond the tropics of Cancer and Capricorn, when seasonal water temperature differences become more marked. It is these differences between summer and winter conditions that separate tropical from subtropical estuaries. Estuaries from the tropics represent one of the most exploited ecosystems in the world (Blaber, 2000). They are rich in biodiversity and may have the highest economic value per hectare relative to any other aquatic environment (Costanza, 1997). Therefore, conservation and protection these water bodies should be on top priority in order to maintain their viability for biodiversity and fisheries production.

### **1.3. Wetlands:**

Wetlands from various geographical belts have been estimated to cover approximately 6% of the earth's surface (Gopal, 1998). They represent transition zones occupying an intermediate position between the dry land and open water (Mukerji and Mandeep, 1998). Due to their wide ranging nature and characteristics, no single definition was ever found to be complete. They are natural and man-made, permanent, temporary or seasonal water bodies. According to the International Ramsar Convention (1971), wetlands are defined as:

*“Areas of marsh, fen, peat-lands or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including area of marine water; the depth of which at low tides does not exceed six meter”*

One most important characteristic of all wetlands is that the substrate must be either covered or fully saturated with water, at least for part of the year (Mukerji and Mandeep, 1998; Gopal, 1998). Ecologically, wetlands have a very significant role in biodiversity, inhabiting many species of zoo and phytoplankton, macrophytes and larger animals like fishes, shrimps, and molluscs, etc (Stevens, 1998).

### **1.3.1. Types of Wetland:**

Wetlands could be lakes, rivers, streams, saltpans, salt marshes, meadows, natural or artificial reservoirs, mangroves, shoreline, seasonally flooded riverbanks, etc. Dugan (1990) classified salt wetlands into: (i) marine; (ii) estuarine; (iii) lagoon; and (iv) salt lakes. The fresh water wetlands are essentially of three types (Gopal, 1998): (i) riverine, like permanent rivers, streams, water falls, inland deltas, temporary, seasonal, and irregular streams and rivers, riverine flood plains and basins; (ii) lacustrine or rain fed lakes, small or large size; and (iii) palustrine like fresh water swamps, marshes, peat lands, etc.

### **1.3.2. The Environment of Wetlands:**

Out of the 71% of earth covered by water, 3% of it is fresh water. This fresh water divided into icecap and glacier (77.2%), ground water and soil moisture (22.4%), lake and swamps (0.35%), atmospheric water vapour (0.04%) and in stream (0.01%). Wetlands have been estimated to cover approximately 6% of the earth's surface (Gopal, 1998). The lakes and swamps contain approximately 0.00011% of the total global water (Sarkar, 1998).

Wetlands play an important role as water storage and flood control. They contain a significant floral and faunal habitats, gene pool, protecting the shoreline, sustaining the economy of the people, recreational facilities, etc. (Stevens, 1998). They also act as carbon sinks due to their relatively high

rates of primary productivity and accumulation of organic matter in the sediments. Wetlands also contribute significantly to the fluxes of nitrogen, sulfur and phosphorus, and possibly some pollutants such as heavy metals (Sarkar, 1998).

During last three decades, these wetland habitats in the world faced major threats that partially led to their destruction and loss of dependant biota. The various threats include siltation due to water inflow, deforestation, etc.; water pollution, agricultural pesticides, fertilizers, domestic and industrial effluents, sewage, mine drainage; eutrophication, encroachment through agricultural operations, aquaculture, pisciculture, etc.; reduction in arrival of migratory birds, exploitation of resources like fisheries, load of tourism and its development, etc. Sarkar (1998).

#### **1.4. Coastal Zones of India:**

India has an area of 3,287,782 km<sup>2</sup>, located in the northern hemisphere, between 8° 4' and 37° 6' north latitude, and 67° 7' and 97° 25' east longitude. The country is characterized by a variety of physical features and ecological and climatic conditions ranging from driest to wettest and hottest to coldest with different combinations of rainfall, temperature, humidity, physiography and biotic stresses. Physiographically, it is divided into four main regions: the northern mountains, the great plains, the peninsular plateaus and the sea coasts and islands (Kumar, 1995). The mainland



coastline admeasures to ~ 6100 km length, bounded by the Arabian Sea to the west, the Bay of Bengal to the east and the Indian Ocean to the south.

The west coast extends from Rann of Kutuch (Gujarat) in the north to Kanyakumari (Tamil Nadu) in the south, with a length of about 3,287 km. it is characterized by cliffs, promontories, lakes, lagoons and back waters. Mangrove swamps and salt marshes line the coasts at some places, especially along the tidal estuaries (Wagle and Vora, 1980). The central west coast of India, includes the state of Goa, is marked by large hills bordered by narrow alluvial plains followed by an indented coastline with bays, estuaries and sandy stretches (Wagle, 1982). The coastal zone along the west coast of the country varies from 50 to 60 km from shoreline in Khambhat region to 0 to 15 km in Maharashtra, Goa, Karnataka, and Kerala.

India's extensive geographical and morphological stretch contains rich diversity of inland and coastal wetland habitats. It has ~ 4.1 million hectares of natural, and ~ 2.6 million hectares of man-made wetlands (Mukerji and Mandeep, 1998). Deltas and estuaries are quite significant among the features of Indian shores. However, deltaic region are more predominant, to the eastern coast and estuaries largely occur on the western shore, due to the gradual slope towards east and steep topography to the west, respectively (Ahmed, 1972).

#### **1.4.1. The coastal ecosystem of the State of Goa:**

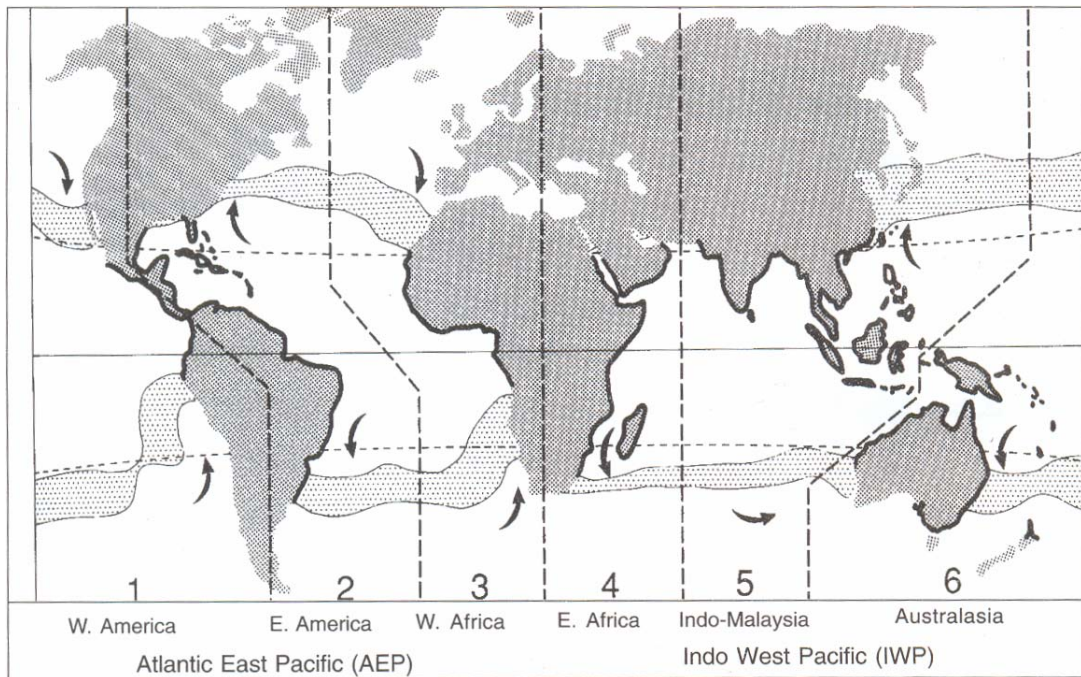
The coastal plains of Goa, ranges between 2 to 35 km in width, and consists of sandy beaches, sea cliffs, promontories, estuaries, spits, sand dunes, weathering rocks and wave cut platforms, wooded or bare hill slopes which are traversed by the riverine system that experience tides. The rivers/ estuaries from the state are considered to be drowned valleys of microtidal (0.001 – 2.4 m) nature (Ahmed, 1972). The tidal effect can be felt more than 40 km in the hinterland (Shetye *et al.*, 2007). Small islands and shoals are observed within water bodies, while fringing and patchy mangrove swamps are common along the water bodies of mainland and islands in the estuaries (Jagtap, 1985). The southern sector is mostly occupied by evergreen forests (Wagle, 1987; Mascarenhas, 1999a; 2000).

The coastal plains comprise an intricate system of wetlands, tidal marshes and cultivated paddy fields, all intersected by canals, inland lakes, bays, lagoons and creeks (Rao *et al.*, 1985). All the rivers and the extensive backwaters are governed by regular tides, which raise or lower water levels between two or three meters daily. The prominent lowlands adjacent to most of the rivers are locally known as ‘khazan lands’, a term which denotes land reclaimed by gradual filling of the shallow seas. Most of these lowlands are almost at and even below sea level (Mascarenhas, 1999a).

## 1.5. Mangroves:

Tidal swamps in tropics and subtropics, formed by deposition of alluvial sediments of recent origin, are characterized by dense and fringing growth of shrubs and trees, usually referred to as mangrove swamps, mangrove forests or tidal forests (Knox, 2001). Mangrove habitats are defined as sea-land interface woody plants in protected intertidal zone, usually growing between high spring tide and mean sea level. The term mangrove is formed by two words, the Portuguese “*Mangue*”, which means an individual species of mangrove, and the English word “*grove*”; therefore, mangrove can be said to be a grove of trees and shrubs (Jagtap, 1985; Singh and Odaki, 2004; Ranade, 2007). The word mangrove refers to individual trees, whereas the mangrove plant community is called a “*mangal*”.

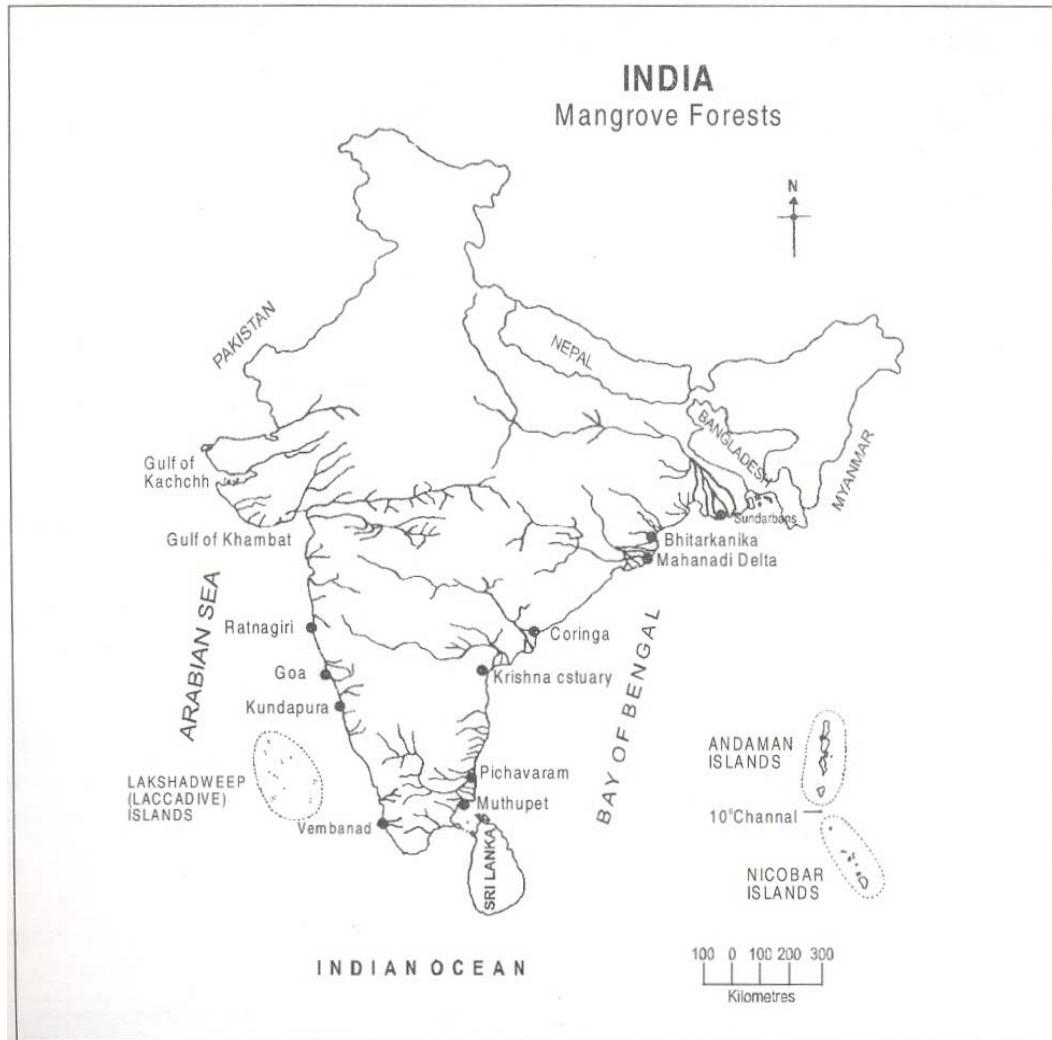
Presently, mangrove ecosystems cover an area of about 20 million hectares world wide (English *et al.*, 1997). They have been reported in 112 countries, covering about 60 – 75% of tropical coastline (Figure 1.1). Mangrove in India covers approximately 0.6 million hectares (about 6,700 km<sup>2</sup>), which is about 3% of the total global mangrove coverage (Mukerji and Mandeep, 1998; Ranade, 2007). The eastern coast of India possesses about 70% of the total Indian mangroves. This includes the Sunderban (the largest single block of mangrove ecosystem in the world), located in the estuary of River Ganges (Hoq, 2007). About 12% is distributed along the western coast, while the remaining 18% is distributed around the Andaman and Nicobar Islands (Ranade, 2007) (Figure 1.2). There are three types of



**Figure 1.1.** Distribution of mangrove in six geographic regions of the world  
(Source: Duke, 1992).

mangroves in India *viz.* deltaic, backwater–estuarine and insular mangroves (Rajendran and Sanjeevi, 2004). About 61 of mangrove species have been reported in the Indian subcontinent (Krishnamurthy *et al.*, 1987; Singh and Odaki, 2004). Jagtap (1985) has reported 15 species in the State of Goa (Table 1.1). During the last three decades, mangrove ecosystems have been receiving much global importance and attention by scientific communities, environmentalists, as well as coastal zone managers (Naskar and Mandal, 1999; Singh and Odaki, 2004).

Within the broad geographic range, mangroves grow in environmental settings ranging from high humid to extremely arid conditions. Mangroves form the dominant intertidal vegetation in tropical and subtropical regions (Blasco, 1984). They generally match the 20 °C isotherms in both hemispheres, suggesting that water temperature is the most significant factor influencing their distribution. The presence of mangroves have been observed to correlate with areas where the water temperature of the warmest month exceeds 24 °C; also that their northern and southern limits correlates reasonably well with 16 °C isotherm for the air temperature of the coldest months (Hutchings and Saenger, 1987). Mangroves are highly evolved communities adapted to tolerate high salinity and environmental stress by developing special anatomical, physiological and reproductive features (Jagtap, 1985; Clark, 1996; Knox, 2001; Kathiresan and Qasim, 2005; Ranade, 2007).



**Figure 1.2.** Distribution of mangrove ( ● ) in the Indian subcontinent (Source: Kathiresan and Qasim, 2005).

**Table 1.1.** List of mangrove species and their associates in Goa rivers and estuaries (Source: Jagtap, 1985).

	<b>Mangrove Species</b>	<b>Associated Mangrove Species</b>
1	<i>Rhizophora mucronata</i>	<i>Derris heterophylla</i>
2	<i>R. apiculata</i>	<i>Clerodendron inerme</i>
3	<i>Avicennia officinalis</i>	<i>Acrostichum aureum</i>
4	<i>A. marina</i>	<i>Cyperus spp.</i>
5	<i>A. alba</i>	<i>Porteresia coarctata</i>
6	<i>Sonneratia alba</i>	<i>Ceasalpinia crista</i>
7	<i>S. caseolaris</i>	<i>Salvadora persica</i>
8	<i>Exoecaria agallocha</i>	<i>Halophila beccarii</i>
9	<i>Acanthus ilicifolius</i>	<i>Lanea grandis</i>
10	<i>Kandelia candel</i>	<i>Abrus precatorius</i>
11	<i>Bruguiera gymnorhiza</i>	<i>Thespesia populnea</i>
12	<i>B. cylindrica</i>	
13	<i>Ceriops tagal</i>	
14	<i>Aegiceras corniculatum</i>	
15	<i>Lumnitzera racemosa</i>	

There are more than 80 species of mangroves occurring in various parts of the world, either as herbs, shrubs or tall trees (Blaber, 2000). They can form dense forest in intertidal habitats subject to having favorable conditions; however, a few species form a massive canopy (Jayasurya *et al*, 2005). They display extreme variations in plant composition, forest structure, and growth rate. Mangrove forests can vary from a narrow fringe along the banks of an estuary to dense stands covering many square kilometers. Monospecific stands of *Avicennia spp.* are characteristic of large intertidal regions of many subtropical estuaries and may also form a narrow fringe along tropical systems. Some mangrove forests in the tropics have a complex zonation, may contain up to 17 species of trees (Hutchings and saenger, 1987).

The physical structure of mangroves greatly influence the faunal, particularly fish and invertebrates, composition. Their aerial and pneumatophores prop roots, trunks, and fallen branches and leaves make a complex habitat rich in detritus (decomposed vegetative matter), and give shelter for the juveniles of fishes, crustaceans, shell fishes and other invertebrates, both on the trees and burrowing in the mud. Also, the roots trap the rich nutrient laden soil and provide a favorable ground for the growth of many species and prevent soil erosion. The whole suite of mangroves and their associated biotic and abiotic conditions forms one of the core habitats of tropical estuaries (Blaber, 2000).



Despite the fact that nutrients in the tropical marine ecosystems are generally low (Qasim and Wafar, 1990), mangrove ecosystems are considered to be the most productive and complex ecosystem though inhabit in relatively stressed environment, and frequently dominate (Naskar and Mandal, 1999). The ambience being rich in organic production and nutrients, provide an ideal nursery ground for many economically aquatic as well as terrestrial organisms (Manson *et al.*, 2005).

#### **1.6. The Edible Oyster (*Crassostrea*):**

Mangrove ecosystems support small scale fisheries and produce nearly one million tones of fin fishes, molluscs, crabs and shrimps (Rajendran and Sanjeevi, 2004). These habitats play an important role in the socio-economical interest of the coastal people as they can provide jobs in rural areas in agriculture, forestry, fisheries and the tourism industry (Clark, 1996). About one million people over the world are dependent on mangrove associated fisheries (Rajendran and Sanjeevi, 2004).

The edible oysters belong to phylum Mollusca and Class Bivalvia. There are Over 100 species of edible oysters have been distributed all over the world and found distributed in all temperate and tropical coasts (Santhanam *et al.*, 1990). They are capable of tolerating a wide range of salinity. *Crassostrea sp.* shells are more elongated and more deeply cupped, and hence are called cupped oysters. They contribute a great tonnage of animal protein in the food market (Korringa, 1976). Its tender flesh forms a cheaper, nutritious and easily digestible food source.

*Crassostrea madrasensis* (Preston) and *C. gryphoides* (Schlotheim) have been reported to be common to the Indian coasts (Santhanam *et al.*, 1990). They possess greater efficiency in filtering water making them possible to live in highly turbid waters. They are occurring in the same habitat and show marked similarity. They can not be separated on the basis of their external shell morphology (Siddiqui and Ahmed, 2002). However, they could easily be identified from the difference of colour in their inner margins and the adductor muscle scar (White in *C. gryphoides* and purplish or dark in *C. madrasensis*). They are found attached to hard substratum (Rocks, dead shells, concrete cements, etc.) in overcrowded colonies.

Variations in the shape of the oyster shells are likely within the same species from the same area due to overcrowding, orientation, substratum and ecological conditions (Quayle and Newkirk, 1989). Such variations cause great difficulties in the identification of oysters, leading to disagreements among researchers.

## **1.7. Remote Sensing and GIS Techniques:**

### **1.7.1. Remote Sensing (RS):**

Remote sensing data basically consists of wavelength - intensity information, acquired by collecting the electromagnetic radiation reflecting from the object at specific wavelengths and measuring its intensity.

Lillesand *et al.* (2004) defined remote sensing as:

*“The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation”*

Electromagnetic energy sensors are operated from airborne (airplanes, air balloons, etc.) and space borne (satellites, etc.) platforms. The data acquired of reflections and emissions from different earth features are analyzed to acquire desired information about the resources under investigation (Hunt, 1980; Lillesand *et al.* 2004). This whole process could be divided into data acquisition and data analysis

Various earth features manifest very distinctive spectral reflectance and/or emittance characteristics result in spectral patterns. Each feature subjected to electromagnetic energy, responses in a different manner depending on its type and associated conditions. These distinguished responses are referred to as spectral signatures or patterns. The reflected signals are detected by definite sensors and recorded either photographically or electronically (photographs or images). The pictorial images or digital data are visually interpreted by experts in the respective fields in order to qualitatively evaluating the spatial patterns in the images, and identify the various features to extract the required information. Computer-aided analytical techniques could also be used for digital image interpretation.

Collection of reference data is important and helpful in RS (Lillesand *et al.*, 2004). Acquisition of reference data involves collection of measurements and observations about the objects, areas, or phenomena that are being sensed remotely. Field check, old maps, photographs, or data, and geographical positioning (GPS) of the study area are compared with the new images in order to assist in the interpretation process, and verify the information extracted from the RS data. Reference data are commonly referred to as “ground truth”.

### **1.7.2. Geographical information Systems (GIS):**

The Geographical Information System (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geographically referenced data (Lyon and McCarthy, 1995; Chang, 2006). GIS is defined by ESRI as (Chandra and Gosh, 2006):

*“An organized collection of computer hardware, software, geographical data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information”*

These systems are capable of handling both locational data and attribute data about any feature. These attributes might include descriptive information about a given point, line, or area of a feature. The locational data can be also called “spatial data”, which gives information about the geometrical orientation, shape and size of a feature, and its relative position

with respect to the position of other features. The attribute data is called “non-spatial data”, which gives information about various attributes such as length, area, population, acreage, names, etc. The most important benefits of a GIS are its ability to spatially interrelate multiple types of information stemming from a range of sources (Lillesand *et al.*, 2004).

GIS requires various components to work comprehensively with geographically referenced data. These components are: i) computer system (hardware and operating system); ii) GIS software; iii) spatial data; iv) data management and analysis procedures; and v) personnel to operate the GIS (Chang, 2006; Chandra and Ghosh, 2006).

### **1.7.3. Application of RS and GIS in mapping mangrove ecosystems:**

Remote sensing and GIS data have been proved to be extremely useful in providing information on various components of coastal environment, such as conditions of coastal habitats, mapping of mangrove and their status, coastal landforms and shoreline changes, tidal boundaries, brackish water areas, suspended sediment dynamics, coastal currents, pollution, etc. (Anon, 2003). Sometimes, RS images can also be used for quantitative measurements of some properties of landscape surface (Lillesand *et al.*, 2004).

Those tools can be of a great help for periodic preparation of accurate inventories, managing and monitoring of natural resources. Remote sensing techniques provide precise, rapid and repetitive information about the

earth's surface including the area covered by water, agriculture, forestry, geography, geology, archeology, weather and climate, marine environment, water resources management and assessment, engineering, land use / land cover mapping, etc. (Burrough, 1986; Engel *et al.*, 1993; Fedra, 1993; Congalton and Gran, 1995; Demers, 2000; Chandra and Ghosh, 2006).

Data generated from the Indian satellites found to be extremely useful in creating baseline inventory of coastal wetlands, coral reef, mangroves, monitoring of protected areas, selecting sites for brackish water aquaculture, detecting shoreline changes, studying coastal land forms, estimating suspended sediments concentration and assessing the impact of engineering structures on suspended sediment patterns (Untawale *et al.*, 1982; Anon, 1992; Jagtap *et al.*, 1994; Nayak and Bahuguna, 2001; Sathe and Sawkar, 2003; Anon, 2003).

### **1.8. Literature Review:**

Mangrove vegetation has been recorded as early as 305 B.C., when Theophrastus reported it in his "*Historia Plantarum*", as cited by Jagtap (1985). Later, enormous amount of studies have been carried out on different aspects of mangrove vegetation and its ambient environment, internationally and in the Indian subcontinent.

Enormous amount of data on the ecology of the Indian mangroves have been collected during the recent past by Blasco (1977); Chai (1980); Jagtap *et al.* (1993); Ambasht and Ambasht (1998); Untawale and Jagtap (1999);

Naskar and Mandal (1999); Rao and Suresh (2001); Upadhyay *et al.* (2002); Jagtap *et al.* (2002); Blasco and Aizpuru (2002); Jagtap *et al.* (2003); Manjappa *et al.* (2003); Kathiresan and Qasim (2005); and Untawale (2006).

Hydrographic and environmental features relevant to estuarine system of Goa have been investigated in detail, and the information exist in several research documents such as Dehadrai and Bhargava (1972); Das *et al.* (1972); Bhargava *et al.* (1973); Rao (1974); Goswami and Singbal (1974); Singbal (1976); Dalal (1976); Parulekar *et al.* (1980); Qasim and Sen Gupta (1981); De Sousa *et al.* (1981); De Sousa and Sen Gupta (1986); Ansari (1988); Rivonkar (1991); Rattan (1994); Mascarenhas (1999b); Sarma *et al.* (2001); Nayak (2002); and Qasim (2004). Environmental features of the mangrove ecosystem of Goa have been studied by Untawale *et al.* (1973); Bhosle *et al.* (1976); Kumari (1978); Untawale and Parulekar (1976); Jagtap (1985, 1987); Wafar (1987); Manjappa *et al.* (2003); Alvares (2002); and Anon (2004).

Coastal wetland and vegetation maps prepared from remote sensing data have been extensively used worldwide for the effective management of marine natural resources (Bartlett and Klemas, 1980; Crowell *et al.*, 1991; Nayak, 1993; Williams and Lyon, 1995; Klemow, 1998; Sajeev and Subramanian, 2003). Remote sensing and GIS tools have been utilized for evaluating the coastal environments of India, including the State of Goa, by Nayak *et al.* (1985); Roy *et al.* (1985); Roy *et al.* (1991); Anon (1992);

Nayak *et al.* (1996); Ramachandran *et al.* (1998); Jagtap *et al.* (2001); Raghavan *et al.* (2001); Nagamani and Ramachandran (2003); Anon (2003); Ramachandran *et al.* (2005); Deshmukh *et al.* (2005).

Ramachandaran *et al.* (2005) estimated mangrove cover changes damaged by the influence of December 2004 tsunami. A study by Ramachandaran *et al.* (1998) differentiate mangroves from other terrestrial forest types and to identify changes in mangrove vegetation in Tamil Nadu and Andaman and Nicobar group of islands using MSS, TM and IRS bands. Assessment of community-based restoration of Pichavaram mangrove (Tamil Nadu) was done by using remote sensing data (Selvam *et al.*, 2003).

Very few attempts have been made to identify mangroves at species level using satellite data (Nayak and Bahuguna, 2001). Major mangrove types and subtypes of the Bay of Bengal coastline were mapped by Blasco and Aizpuru (2002) using high resolution satellite data (SPOT products). Community zonation of selected mangrove habitats in mangrove dominated coastal areas of India has also been studied using IRS 1C / 1D LISS III and PAN satellite data (Anon, 2003).

Mapping of coastal vegetation along the Goa coast is reported by Kunte and Wagle (1994; 1997). Satellite data of MSS, IRS have been used to study mangrove distribution in some coastal parts of Goa by Untawale *et al.* (1982); Anon (1992); Shailesh and Bahuguna (2001); Sathe and Sawkar (2003); Anon (2003) and Murali *et al.*, (2006). Aerial photographs have



been used to differentiate mangroves from other terrestrial vegetation and the distributions of the different classes of dominant mangrove species along Goa coast (Untawale *et al.*, 1982; Jagtap, 1985; Jagtap *et al.*, 1994). Remote sensing and GIS tools have also been carried out in integrated management of the coastal zone in Goa De Souza (2006). However, very little efforts have been made to study the change detection of the coastal zone features (including mangroves) in limited areas of Goa using multi-temporal satellite data (Sathe and Sawkar, 2003; Murali *et al.*, 2006). Therefore, there is a great scope for evaluating the change in land use pattern in mangrove habitats from Goa considering intensive anthropogenic pressures on these habitats during the recent past.

Mangrove ecosystems inhabit various kinds of fauna of ecological and socioeconomic significance (Ajana, 1980; Jagtap, 1985). Environmental factors affecting growth and biology of bivalves have been reported (Seed, 1968; Widdows and Bayne, 1971; Walne, 1972; Rao *et al.*, 1975; Qasim *et al.*, 1977; Mahadevan and Nayar, 1987; Roustaian, 1994; Siddique and Ahmed, 2002; Turner, 2006; Bergquist *et al.*, 2006). Ecological studies of benthic fauna and edible bivalve including oysters from the coast of Goa have been investigated to some extent (Parulekar *et al.*, 1980; 1982; 1984; Mahadevan and Nayar, 1987; Rivonkar, 1991; Rivonkar and Parulekar, 1998).

Galstoff (1931) attempted studies on allometric relationships of the pearl oyster, *Pinctada sp.* Similar investigations earlier on Indian bivalves were

carried out by various researchers (Rao and Nayar, 1956; Parulekar *et al.*, 1973; Durve, 1973; Alagarswami and Chellam, 1977; Nair *et al.*, 1978; Ansari *et al.*, 1978; Hickman, 1979; Mohan, 1980; Chatterji *et al.*, 1984; 1985; Parulekar *et al.*, 1984; Schaefer *et al.*, 1985; Rivonkar, 1991; Blaber, 2000). Lucas and Beninger (1985) reviewed and assessed different physiological condition indices those most commonly used for the understanding of marine bivalves. These indices of oysters were also studied by Baird (1958); Gabbott and Stephenson (1974); Lawrence and Scott (1982); Beninger and Lucas (1984); Ruiz *et al.* (1992); Austin *et al.* (1993) and Schumacker *et al.* (1998). Percentage edibility of *C. gryphoides* from India was investigated by Durve (1964) and Nagabhushanam and Bidarkar (1978).

Seasonal variations of biochemical composition of the marine bivalves around the world have been carried out to find their nutritive potentials (Galstoff, 1964; Williams, 1969; Ansell, 1972; Dame, 1972; Gabbott and Bayne, 1973; Seed, 1973; Holland and Spencer, 1973; Gabbott and Stephenson, 1974; Dare and Edwards, 1975; Lubet, 1976; Mann, 1979; Jones *et al.*, 1979; Zandee *et al.*, 1980; Ruiz *et al.*, 1992; Páez-Osuna *et al.*, 1993; Robert *et al.*, 1993; Patrick *et al.*, 2006; Dridi *et al.*, 2007). Similar studies for Indian bivalves were also carried out by Venkataraman and Chari (1951); Durve and Bal (1961); Durve (1964); Saraswathy and Nair (1969); Jagabhushanam and Deshmukh (1974); Wafar *et al.* (1976); Kumari *et al.* (1977); Shafee (1978); Nagabhushanam and Bidarkar (1978);

Lakshmanan and Nambisan (1980); Stephen (1980a); (1980b); Ansari *et al.* (1981); Joseph and Madhyastha (1984); Chatterji *et al.* (1985); Ponniah (1988); Balasubrahmanyam and Natarajan (1988); Rivonkar and Parulekar (1995) and Mohan and Kalyani (1998).

Various types of trace and heavy metals ultimately find their ways and get accumulated and recycled in the marine environment. In depth studies and investigations have been carried out on trace metals in estuarine environment and biota therein. A number of organisms serve as indicators of pollution in the marine environment (Leatherland and Burton, 1974; Phillips, 1977a; Anil and Wagh, 1988). Concentrations of trace metals in the waters off the west coast of India have been investigated to a great deal (Sankaranarayanan and Reddy, 1973; Fondekar and Reddy, 1974; 1976; Zingde *et al.*, 1976; Singbal *et al.*, 1978; Sen Gupta *et al.*, 1978; Zingde *et al.*, 1979; George and Sawkar, 1981; George *et al.*, 1984; Babukutty and Chacko, 1992; Alagarsamy, 2006) and the Andaman Sea (Kureishy *et al.*, 1981; Kureishy *et al.*, 1983). Distribution of trace metals in the mangrove environment and their associated flora and marine algae from Goa also have been investigated for metal concentrations to a lesser extent (Agadi *et al.*, 1978; Untawale *et al.*, 1980; Jagtap, 1983; Jingchun *et al.*, 2006). Jagtap and Untawale (1980) studied the Effect of Petroleum Products on Mangrove Seedlings.

Trace metal concentrations in different species of marine bivalves, particularly mussels *Mytilus spp.*, were widely studied for its indicator

potential and used as indicator parameter for evaluating and monitoring the coastal pollution (Talbot *et al.*, 1976; Bourget and Cossa, 1976; Phillips, 1976a; 1976b; 1977a; 1977b; 1978; Nair *et al.*, 1977; D'Silva and Kureishy, 1978; Bhosle and Matondkar, 1978; Popham *et al.*, 1980; Gordon *et al.*, 1980; Talbot, 1985; 1987; Borchardt *et al.*, 1988; Fang and Wang, 2006). Similarly, *Pecten maximus* and *Modiolus modiolus* were also studied by Segar *et al.* (1971), *Perna viridis* by Rivonkar (1991) and Rivonkar and Parulekar (1998) and *Paphia malabarica* by Kumari *et al.* (2006) for their trace metal concentrations. However, very limited efforts have done in evaluating trace metal concentrations in oysters (Boyden and Romeril, 1974; Sankaranarayanan *et al.*, 1978; D'Silva and Qasim, 1979; Phillips, 1979; Rajendran *et al.*, 1987; Peerzada and Dickinson, 1988).

Measures for sustainable management and conservation/protection of mangrove ecosystem have been the subject of research in the recent past (Chai, 1980; Jagtap, 1985; Nayak, 1993; Chakrabarti, 1995; Clark, 1996; Pomeroy and Katon, 2000; Jagtap *et al.*, 2002; Jagtap *et al.*, 2003; Singh and Odaki 2004; Kathiresan and Qasim, 2005; Bhardwaj, 2007).

Despite the efforts made by various researchers for studying the various aspects of mangrove and oyster ecology, biology and significance, there appears to be lacunas in our knowledge about the situation and recent changes in the mangrove ecosystems of Goa and studying the environmental characteristics and significance of its associated oysters, particularly *C. madrasensis*.

In view of the above literature survey, the following objectives have been decided to be fulfilled:

#### **1.9. The Objectives of the Present Study:**

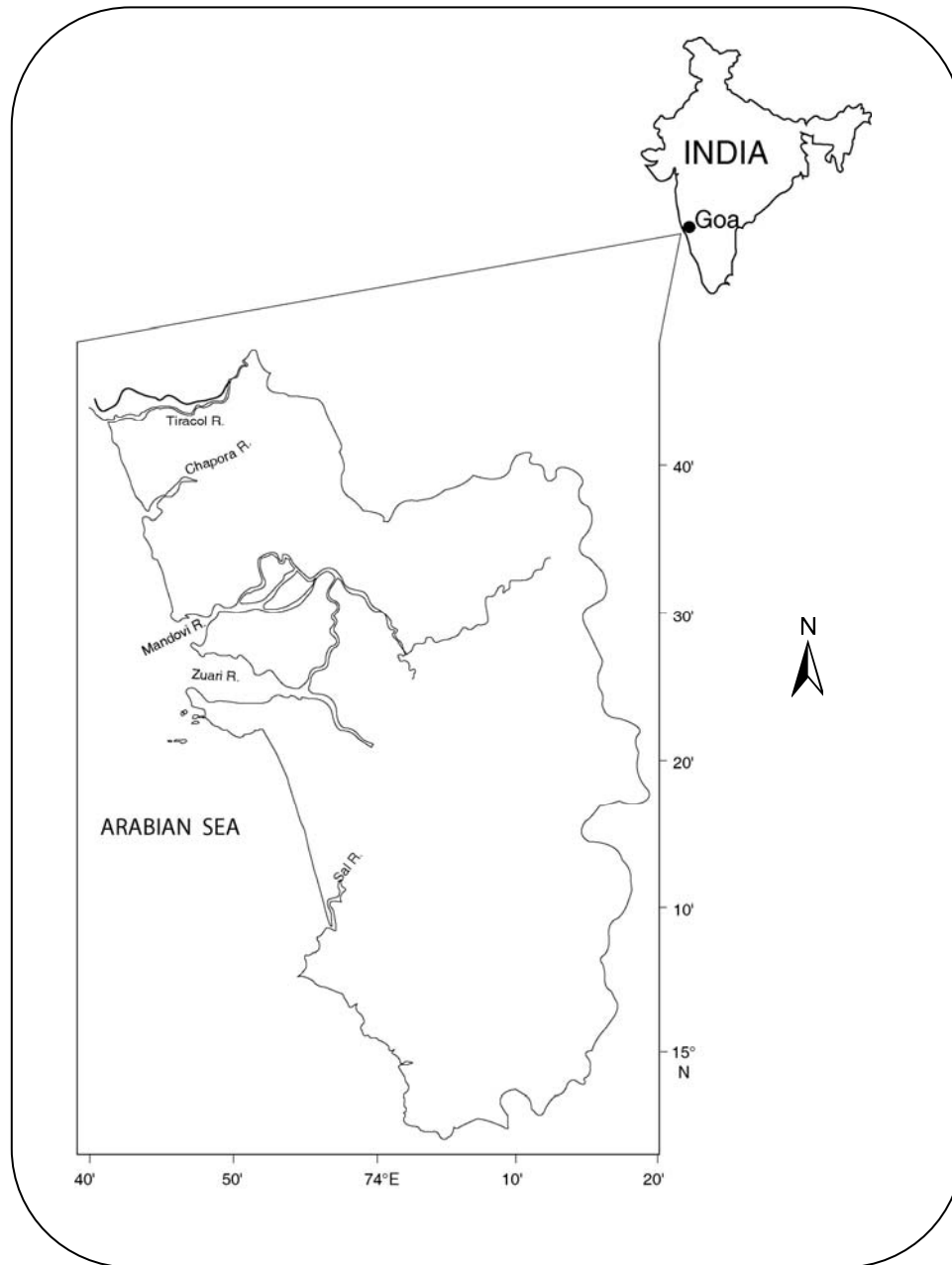
- Detection of land use – land cover changes in mangrove areas.
- To study the environmental characteristics in the selected mangrove ecosystems.
- To study the productivity of oysters (*Crassostrea gryphoides* and *C. madrasensis*), in the mangrove influenced regions.
- To determine the significance of oysters as a bio-indicator to the trace metals pollution in the mangrove ecosystem region.

### STUDY AREA AND METHODOLOGY

#### 2.1. The Study Area:

The state of Goa is located between 15° 44' 30" and 14° 53' 30" N, and 73° 45' and 74° 26' E, along the Central West Coast of India. Its extreme length from north to south is 105 km, its greatest breadth from east to west is 65 km, and its entire area is 3,702 km<sup>2</sup> (Gomes, 1996; Fonseca, 2001). It is bounded by the Terekhol or Araundem River to the north, which separates it from the Maharashtra state, on the east by the Western Ghats, on the west by the Arabian Sea, and on the east and south by the Karnataka State (Figure 2.1). The region is divided into three main regions (De Souza, 1979; Wagle, 1982):

- i) The eastern Sahayadris - The Goa sub region of the Western Ghats, and covers ~ 43% of the state total area.
- ii) The central uplands - It is the tract between the coast and the Ghats. It consists of a chain of rolling hills with gentle to moderate slopes and long, narrow intermediate valleys, and covers ~ 35% of the state area.
- iii) The western coastal plains - The coastal belt accounts for ~ 22% of the total area of Goa.



**Figure 2.1.** Geographical location of the study area.

Goa is organized for administrative purposes into 11 talukas or counties, viz. Ilhas (Tiswadi), Bardez, Salcete, Mormugao, Ponda, Bicholim, Pernem, Quepem, Sanguem, Canacona and Satari.

The state is intersected by numerous rivers, which can be navigated for different purposes. Most of the major rivers, which cut across hinterland formations, originate in the Western Ghats across the border. The two main rivers are Mandovi (61.6 km in length), and Zuari (92.4 km), with their interconnecting Cumbarjua Canal (15 km) form a major estuarine complex. The other rivers are run for short distance as Terekhol (22.4 km), Chapora (28.8 km), Baga (5.4 km), Sal (16.1 km), Talpona (11.2 km), and Galgibag (3.8 km) in length (Esteves, 1966; Fonseca, 2001).

## **2.2. Climate of Goa:**

Goa enjoys a typical tropical warm and humid climate with three seasons throughout the year, the cold/dry season or post-monsoon (October – January), the warm or hot season or pre-monsoon (February – May), and the rainy season or monsoon (June – September). The maximum temperature for the whole year is about 36 °C, and the minimum is about 18 °C; the warmest days in the year are generally in May and the coolest mostly in February.

The mean daily temperature varies slightly, from around 25 °C to about 30 °C, due to the maritime nature of the climate. The average annual temperature remains to 26 °C. The Sahayadris range (Western Ghats)



prevents the cold, dry winds of the inland from sweeping down Goa and hence the state does not experience a normal winter (De Souza, 1979). However, temperature variation remains wider in the eastern region due to the mountainous topography, particularly in December to January, during which the Indian subcontinent experiences the winter.

The state of Goa receives 90% of its rains from the southwest monsoon (during the wet season) as it lies along the coast and on the windward side of the Sahayadris. The average annual rainfall ranges from 2,800 mm to 3,500 mm. About 36% of the annual rains lash Goa in the month of July (Esteves, 1966; De Souza, 1979).

### **2.3. Sampling Stations:**

A rapid survey of oyster beds in association with mangroves was conducted along the estuarine system of Goa, for selection of sampling stations. Oyster beds are under severe exploitation and only empty shells are found in many places. Two sites (Chorao Island and Nerul Creek), rich in mangroves and their associated oyster beds, were selected based upon the preliminary observations and published literature on oyster beds from the state.

#### **2.3.1. Chorao Island (St-1):**

The Chorao Island is located between the Mandovi and the Mapusa Rivers in Goa. The western side of the island is taking a peninsular shape and

occupied by a thick mangrove forest of about 1.78 km<sup>2</sup>. This mangrove forest has been declared by the Government of Goa for the purpose of conservation as Dr. Salem Ali Bird Sanctuary in 1988. About 14 species of mangrove, 6 species of algae, 13 species of fishes, 34 species of resident birds and 14 species of migratory birds, in addition to reptiles and mammals, etc. were reported in Chorao island (Anon, 2003). The geographical location of the station is 15° 30" 39' latitude and 73° 51" 46' longitude (Figure 2.2).

### **2.3.2. Nerul Creek (St-2):**

The Nerul creek is opened into the Aguada Bay of Mandovi Estuary. It extends inside the land in U-shape to a length of about 8.5 km. It is navigated by small fishing boats, and bounded by fringing and patchy mangrove habitats. The geographical location of the sampling station is located in 15° 30" 37' latitude and 73° 46" 45' longitude, below the Nerul bridge (Figure 2.2).

## **2.4. Methodology:**

### **2.4.1. Change Detection of Mangrove Environment by Using Remote Sensing and GIS Applications:**

The high tide and cloud cover modify and reduce the signatures reflected from the various features of tidal zones. It is always preferred to choose the

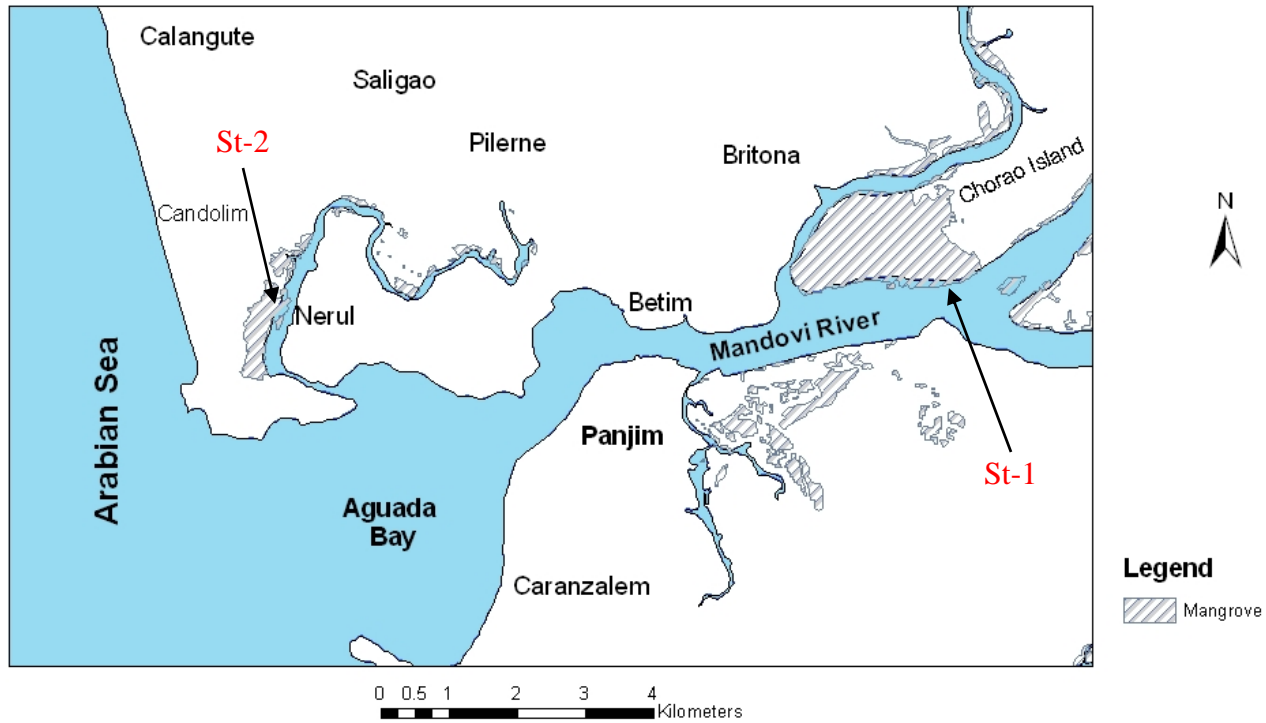


Figure 2.2. Location of sampling sites along Mandovi Estuary.

data acquired at low tides and clear cloud cover conditions to have better spectral signals for studying coastal features. Time lapsed False Color Composites (FCC) imageries of IRS-1C LISSIII, IRS-1D LISSIII and IRS-P6 LISSIII of the years 1997, 2001 and 2006, respectively (Table 2.1), with resolution of 23.5 m, acquired from the National Remote Sensing Agency (NRSA), Hyderabad (Figure 2.3).

It is very essential to incorporate the other related ground information on the manually interpreted map (Ramachandran *et al.*, 1998). For this purpose, ancillary data, i.e. topographic maps prepared by Survey of India (SOI), pertaining to the state of Goa (48E/10, 48E/13, 48E/14, 48E/15, 48E/16, 48I/2, 48I/3, 48I/4, 48I/6, 48I/7, 48I/8, 48J/1 and 48J/5) on 1:50,000 scale for the years 1962 - 1979, were obtained from the library of the National Institute of Oceanography (NIO). These toposheets were scanned and converted to image format used for extracting terrain features such as shore line, contour lines, roads, railways, water bodies, major rivers and drainage systems. The images were rectified in such a manner that the spatial coordinated correspond to their geographic coordinates. This process is called geo-coding. The geo-coded toposheets after mosaicing were used for registering the satellite imageries to their corresponding geographic coordinates.

The imageries were further resampled using the nearest neighbor resample method. The projection applied in this study was geographic with spheroid Everest and datum undefined. The geo-referenced satellite imageries then

subjected to digital image processing techniques for enhancement, which involved brightness/contrast technique. Enhancement techniques help in improving the visual interpretability of the image by increasing the apparent distinction between the features in the scene (Lillesand *et al.*, 2004).

Various features from the imageries were categorized, depending upon their spectral values, into identified homogeneous groups of pixels. Each group represents various land cover classes. This type of classification is termed “spectral pattern recognition” (Chandra and Gosh, 2006). A supervised classification was performed by selecting appropriate homogeneous representative samples (Training areas) of different surface cover types of interest. Training areas on the satellite imageries were selected based on familiarity with particular geographical area and knowledge of the cover types present on it. Data from set of training areas were evaluated for separability in order to get more accurate classified maps and differentiate various classes (signatures) from one another, as well as to identify the best possible combination of bands for classification. Various measures are expressing the degree of separability of the spectral classes, of which Transformed Divergence (TD) method was applied in the present study because of its efficiency and ease of their computation.

The supervised classification process has performed using maximum likelihood classifier. The resulted classified thematic map was evaluated by

**Table 2.1.** Details of the satellite data used in the investigation.

<b>Date of pass</b>	<b>Satellite</b>	<b>Sensor</b>	<b>Bands (<math>\mu\text{m}</math>)</b>	<b>Pixel resolution (m)</b>
			0.52-0.59 (2)	
11 Feb. 1997	IRS - 1C	LISS III	0.62-0.68 (3)	23.5
			0.77-0.86 (4)	
			0.52-0.59 (2)	
5 Feb. 2001	IRS - 1D	LISS III	0.62-0.68 (3)	23.5
			0.77-0.86 (4)	
			0.52-0.59 (2)	
19 Jan. 2006	IRS - P6	LISS III	0.62-0.68 (3)	23.5
			0.77-0.86 (4)	



11<sup>th</sup> Feb. 1997  
IRS-1C LISS III



5<sup>th</sup> Feb. 2001  
IRS-1D LISS III



19<sup>th</sup> Jan. 2006  
IRS-P6 LISS III

**Figure 2.3.** Time lapsed satellite data used in the study.

performing accuracy assessment of various classes on the ground identified from the image. The classified map was compared with a reference map or by using ground truth information of unknown areas on the reference map for the evaluation accuracy. The relevant ground truth data was collected from different locations of interest, for which, geographical coordinates were noted by using GPS (Garmin *GPS72*).

Ground truth information was then matched with the classified images to check the accuracy of the classification. Error matrix and overall accuracy assessment were estimated. Kappa coefficient ( $k$ ), which indicates how each classification differs from a random classification of the land cover type (Dwivedi *et al.*, 2004), was then calculated. The Kappa coefficient is a measure of the difference between, observed agreement between two maps (as reported by overall accuracy) and the agreement that might be contributed solely by chance matching of two maps. It attempts to provide a measure of agreement that is adjusted for chance and is expressed as follow:

$$Kappa\ Coefficient\ (k) = \frac{(Observed - Expected)}{(1 - Expected)}$$

Where, *Observed* means the overall accuracy; and *Expected* is an estimate of chance agreement to the observed percentage correct.

Each class then was traced and different layers of the different categories of interest were created. The area of mangroves in the three years was



calculated and results were expressed in hectares (ha). The software used in remote sensing and GIS techniques were ERDAS Imagine 8.5 and ArcGIS 8.3. The flowchart for the methodology adopted for coastal land cover change detection is illustrated in Figure 2.4.

## **2.4.2. Samplings:**

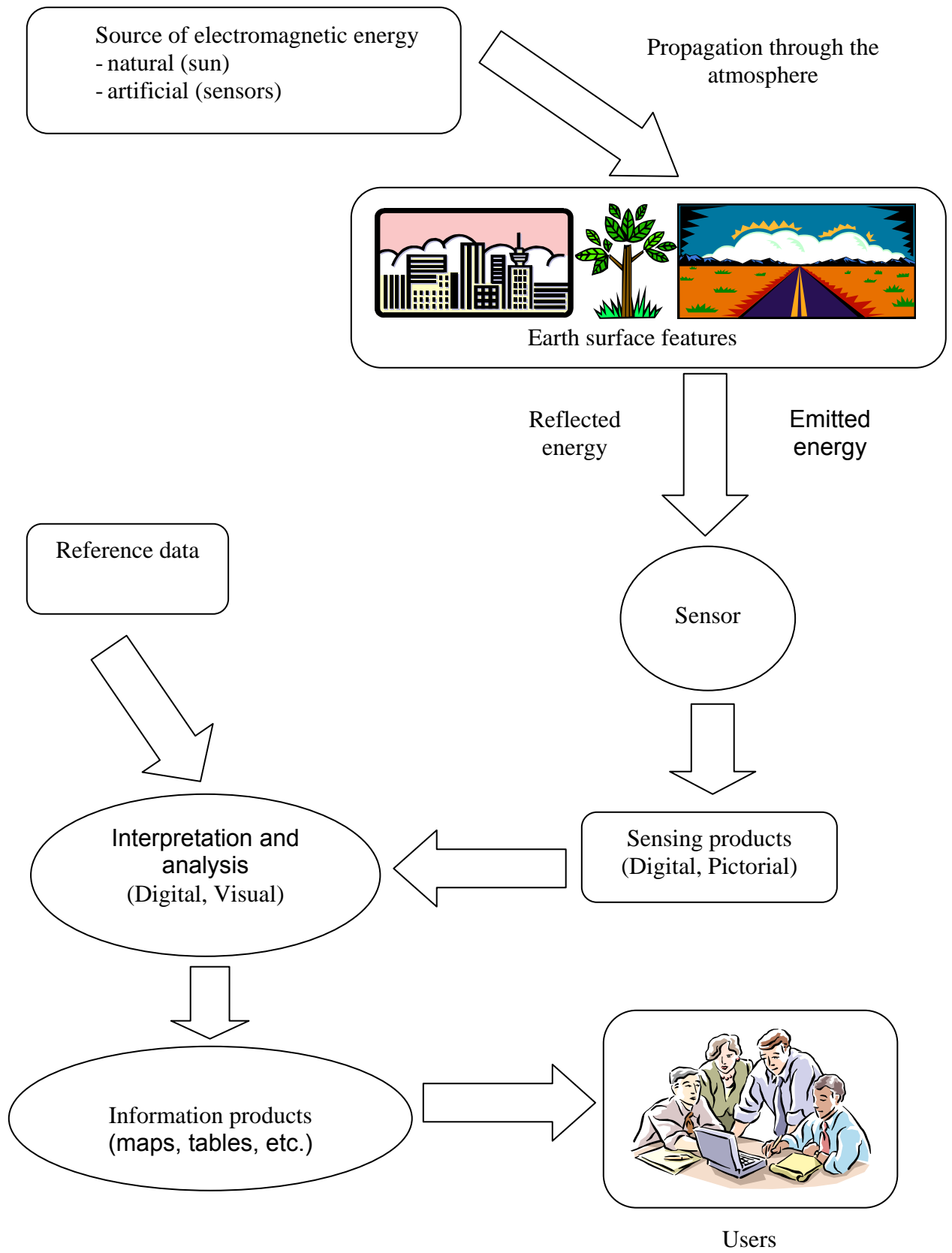
### **2.4.2.1. Water Sampling:**

Monthly samples of water in the above mentioned sampling locations were collected, from August 2005 to July 2006, covering the three seasons *viz*; monsoon (June – September), post-monsoon (October – January) and pre-monsoon (February – May).

### **2.4.2.2. Oyster Sampling:**

The oysters are found attached to hard substratum such as laterite rocks and boulders, from about mid-tide to low tide marks. The beds get exposed at low tides, and hence samplings were carried out at ebb.

Collections of oysters (n = 25) were hand picked from mangrove associated oyster beds at monthly intervals. Density of oyster colonies were assessed using quadrant of 25 cm x 25 cm from each site of collection, which distributed randomly over transects taken perpendicular to the shore line. Due to the morphological similarities, it is difficult to distinguish between the two species (*C. gryphoides* and *C. madrasensis*) externally. The internal



**Figure 2.4.** Flowchart for the methodology used for coastal land cover change detection.

adductor muscle scar was used to distinguish between the two species as described earlier (Siddiqui and Ahmed, 2002). Therefore, the identification of species confirmed in the laboratory after shucking the specimens.

The specimens were transported immediately to the laboratory and cleaned carefully to remove all adhered or attached organisms or fouling materials on the shells. They were then shucked and meat was blotted with filter paper to remove the excess of water, weighed and then dried in the oven at  $60\text{ }^{\circ}\text{C} \pm 2$  until it attained constant weight.

#### **2.4.3. Hydrological Parameters:**

Surface water samples influencing oyster beds at (St-1 and St-2) were collected during the study period for assessing various hydrological parameters. Samples were transported to the laboratory immediately after collections for the analysis of physico-chemical parameters. Various hydrographical aspects such as temperature, salinity, dissolved oxygen, pH, particulate organic carbon and nutrients were analyzed by following standard oceanographic techniques (Strickland and Parsons, 1977; Parsons *et al.*, 1984; Patnaik, 1997; De Medina, 2000), which have been briefly described below.

##### **2.4.3.1. Temperature:**

The water temperature was measured in situ with the help of a mercury thermometer calibrated to  $0.1\text{ }^{\circ}\text{C}$  and the values are expressed as  $^{\circ}\text{C}$ .

#### **2.4.3.2. pH:**

LABINDIA  $\mu$ p (Controlled pH Analyser) was used to estimate pH values in the water samples.

#### **2.4.3.3. Salinity:**

The salinity was analyzed by measuring the electrical conductivity ratio, using Guildline “Autosal” model 8400A salinometer (measurement range: 0.005-42 psu). The readings were then, converted from conductivity ratio to salinity. The values have been expressed in psu.

#### **2.4.3.4. Dissolved Oxygen (DO):**

Dissolved oxygen concentrations were estimated by Winkler’s method. This method involves fixation of dissolved oxygen using Winkler reagents A and B, immediately after collection of the water sample in a dark bottle, followed by titration against standard sodium thiosulfate solution using starch as indicator. The results were expressed in mg/l of water.

#### **2.4.3.5. Particulate Organic Carbon (POC):**

The POC was estimated by wet oxidation method using sulfuric acid-dichromate reagent as described by Parsons *et al.* (1984). The POC values were expressed in  $\mu$ g C/l.

#### **2.4.3.6. Nutrients:**

Nutrients were analyzed in the water samples transported immediately in an ice box to the laboratory. The samples were then analyzed after bringing it to room temperature. The samples were filtered to remove high concentration of phytoplankton and suspended matter.

**Nitrate-Nitrogen ( $NO_3-N$ )** was analyzed by reducing it quantitatively to nitrite by passing through a column containing cadmium filings coated with metallic copper (copper sulfate). Nitrite thus produced was then determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl) ethylenediamine to form highly colored azo dye, which was measured spectrophotometrically at wave length 543 nm, using spectrophotometer Shimadzu UV mini-1240 model. Concentrations of  $NO_3-N$  were expressed in  $\mu\text{g at-N/l}$ .

**Nitrite-Nitrogen ( $NO_2-N$ )** was measured by allowing the nitrite to react with sulfanilamide to form diazo compound, which is reacted with N-(1-naphthyl) ethylenediamine and form highly colored azo dye, as described above in nitrate procedure. This dye is measured spectrophotometrically using wavelength of 543 nm. Nitrite concentrations were expressed in  $\mu\text{g at-N/l}$ .

**Phosphate-Phosphorus ( $PO_4-P$ )** was measured by allowing the water to react with a composite reagent containing ammonium molybdate tetrahydrate solution, sulfuric acid, ascorbic acid and potassium antimonyl-tartrate solution. The resulting complex is reduced to give a blue solution,

which is measured spectrophotometrically at wavelength of 885 nm. Phosphate values have been expressed in µg at-P/l.

#### **2.4.4. Percentage of Edibility (PE) of Oysters:**

The percentage of edible biomass or the Percentage Edibility (PE) values in *C. madrasensis* and *C. gryphoides* was determined by calculating the percentage ratio of the wet meat weight to the whole weight of the individual specimen (Nagabhushanam and Bidarkar, 1977):

$$\text{The Percentage Edibility (PE)} = \frac{\text{Weight of Wet Meat}}{\text{Total Weight of the Oyster}} \times 100$$

#### **2.4.5. Condition Index (CI) of Oysters:**

Various methods have been described for measuring condition indices (CI) values of bivalves. However, the gravimetric formula has less measuring errors, lower coefficient of variation, more easy and rapid to use, and is the most meaningful as an index of current bivalve nutritive status and recent stress (Crosby and Gale, 1990). CI of *C. madrasensis* and *C. gryphoides* were calculated according to the method proposed by Lawrence and Scott (1982), outlined in Quayle and Newkirk (1989), and represented as following:

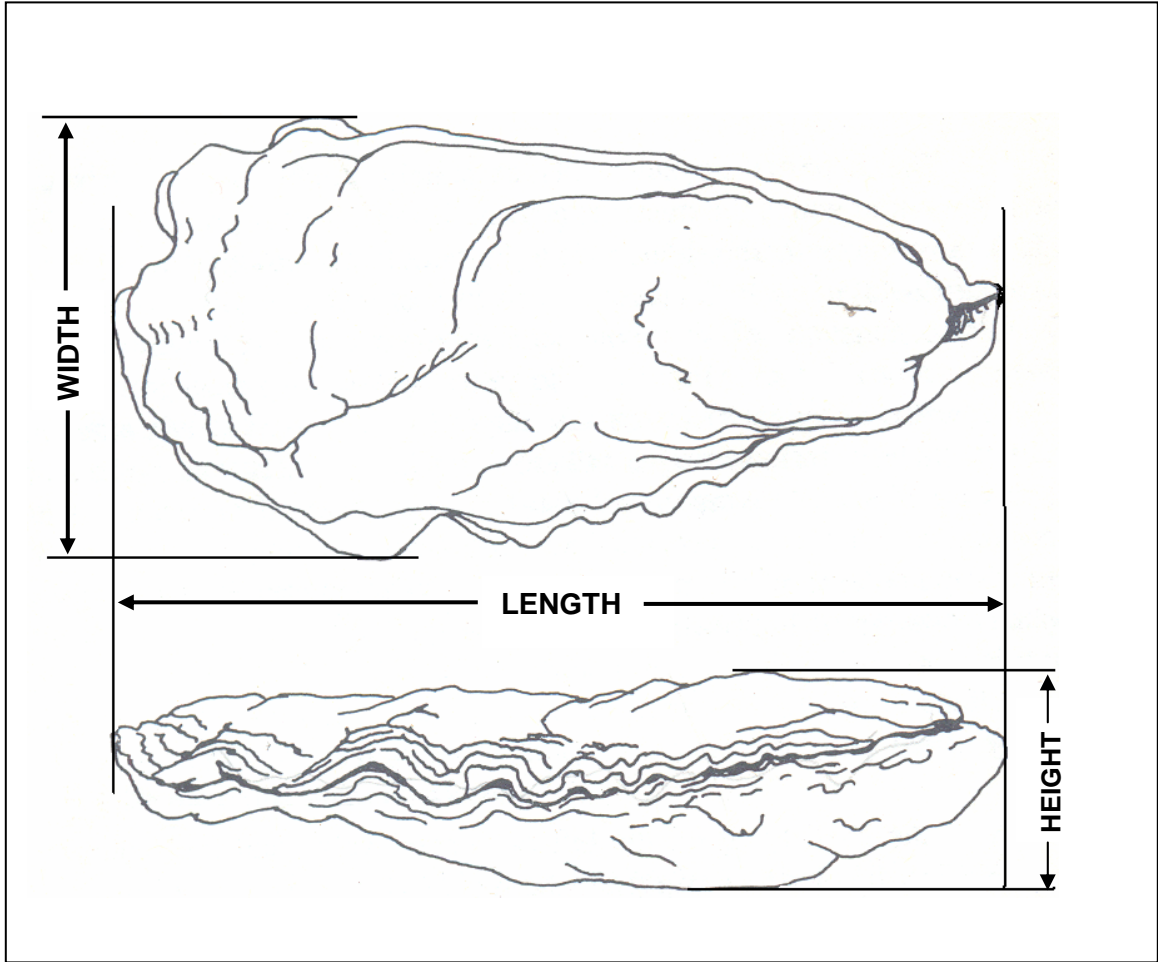
$$\text{The Condition Index (CI)} = \frac{\text{Weight of Dry Meat (g)}}{\text{Volume of Shell Cavity (ml)}} \times 1000$$

In the weighing techniques, only oyster specimens tightly closed and having intact shells were used.

#### **2.4.6. Allometric Relationships in Oysters:**

In order to determine the allometric measurements and relationships, individual specimen was measured for its length, height, width, whole weight, flesh wet weight and dry weight. Shell length, height and width were measured to the nearest 0.02 mm using Vernier calipers. The long axis of the oyster (anterior – posterior axis) was considered as length (Quayle and Newkirk, 1989). The axis perpendicular to the length is called width, which is defined as the maximum distance between ventral and dorsal sides. The shell breadth (height) is the greatest distance between the two closed valves (Figure 2.5). The total weight, shell weight and meat weight of individual specimen was determined by using a mono pan electric balance to an accuracy of 0.01g.

A total of 219 specimens of *C. madrasensis* and 82 specimens of *C. gryphoides* were collected from St-1, during the study period, and a total number of 203 *C. madrasensis* and 115 specimens of *C. gryphoides* were collected from St-2. These data were used to determine the relationships between each of the body dimensions in the two populations of each station and compared the populations with each other. Each oyster species allometric data were pooled together and taken as one class. Regressions



**Figure 2.5.** Dimensional terms applied to oysters (Source: Quayle and Newkirk, 1989).



were calculated by least square method (the straight line is fitted to scattered diagram). These relationships were expressed by the following equation (Hickman, 1979), and is given below:

$$Y = a X^b \quad (\text{or } \log Y = a + b \log X)$$

Where, X and Y are the independent and dependent variables of allometric parameters, respectively whereas a and b are constants estimated by regression. Statistical analyses of relationships including ANOVA were performed using statistical packages.

#### **2.4.7. Biochemical Composition and Caloric values of Oysters:**

Dried meat of the oyster samples of *C. madrasensis* pulverized using mortar and pestle and analyzed for its biochemical constituents and its energy value (caloric value) later, following standard techniques as following:

##### **2.4.7.1. Water Contents:**

Water (moisture) contents of oyster species under investigation were determined gravimetrically, by calculating the difference between the wet weight of the sample and its weight after drying, and the results were expressed in percentage. The formula used for calculation was as:

$$\text{Water Contents (\%)} = \frac{\text{wet weight of flesh} - \text{dry weight of flesh}}{\text{wet weight of flesh}} \times 100$$

#### **2.4.7.2. Protein Contents:**

Proteins were estimated following method of Lowery *et al.* (1951) using Bovine Serum Albumin as a standard. This method is based on the principle of both the reaction between the peptide bonds of protein and copper under alkaline condition to produce  $\text{Cu}^+$ , which reacts with Folin reagent producing blue colour complex as phosphomolybdotungstate gets reduced to heteropolymolybdenum blue by the copper-catalyzed oxidation of aromatic amino acids. The intensity of the blue colour complex depends partly on the tyrosine and tryptophen contents.

One ml of NaOH (1N) was added to 10 mg of the dried flesh of *C. madrsensis*, in test tube, and kept in water bath for 30 minutes to extract protein contents. It was cooled to room temperature (25 °C) and neutralized with 1 ml of 1N HCl. The protein extract thus obtained was centrifuged at 2000 rpm for 10 minutes. One ml of this aliquot was further diluted with distilled water (1:9 v/v). One ml of this solution was allowed to react for 20 minutes with 2.5 ml of mixed reagent (Carbonate-Tartarate-Copper) and 0.5 ml of 1N Folin's reagent. The blue colour developed was measured spectrophotometrically at wavelength 750 nm. The results were expressed as percentage of protein on dry weight basis.

#### **2.4.7.3. Lipid Contents:**

Lipid contents were analyzed by the method of Folch *et al.* (1957). The tissue was extracted with Chloroform – Methanol mixture (2:1, v/v), filtered

and re-extracted with chloroform, allowed to evaporate till dryness. The residue thus obtained was weighed and the percent total lipids were calculated.

10 mg of dried flesh of *C. madrasensis* was homogenized in 10 ml of chloroform methanol mixture (2:1 v/v). The homogenate was centrifuged at 2000 rpm, and the supernatant then was transferred to a pre-weighed test tube through a filter paper, and washed with 0.9% KCl (saline solution) to remove the non-lipid contaminants. The upper layer was discarded by siphoning, and the lower phase was allowed to dry in an oven and weighed as lipid contents. The results were expressed as percentage of lipid on dry weight basis.

#### **2.4.7.4. Carbohydrate Contents:**

Total carbohydrates were estimated by the phenol sulfuric acid method (Dubois *et al.*, 1956) using glucose as a standard. Phenol and sulfuric acid were added to digested sample. The solution turns to a yellow-orange colour as a result of the interaction between the carbohydrates and the phenol. The absorbance was measured at 490 nm, which was proportional to the carbohydrate concentration.

Ten mg of dried flesh sample was digested with 2 ml of 80% H<sub>2</sub>SO<sub>4</sub> for about 20 – 21 hours at room temperature. Two ml of 5% phenol reagent followed by 5 ml of concentrated H<sub>2</sub>SO<sub>4</sub> were added to the digested sample and allowed to cool. The absorbance of the developed brown colour was

measured spectrophotometrically at 490 nm wavelength. The concentrations were expressed as percentage of carbohydrate on dry weight basis.

#### **2.4.7.5. Caloric Value:**

The caloric value (nutritional or food energy value) were estimated by using conversion factors 4.20 cal/mg, 5.56 cal/mg and 9.45 cal/mg dry weights for carbohydrates, proteins and lipids, respectively (Phillips, 1969).

#### **2.4.8. Trace Metals Analysis:**

Water, oysters (*C. madrasensis*) and mature leaves of selected mangrove species from the vicinity of oyster beds were analyzed for trace metals using standard methods as following:

##### **2.4.8.1. Water samples:**

Water samples, from St-1 and St-2, were collected in clean polythene bottles to avoid any external contaminations and stored by reducing the pH below 4 by adding 1N HCl. They were digested further by adding concentrated HNO<sub>3</sub>, and evaporated by continuous heating on a hot plate. The solution then passed through a filter paper (no. 42), and diluted to 100 ml with distilled water.

#### **2.4.8.2. Oyster samples:**

Flesh of *C. madrasensis* from fresh samples was removed using clean scissors and forceps under hygienic conditions to avoid contamination of any sort. Meat then obtained was dried in an oven for 24 hours at 80 °C to a constant weight. The dried meat was pulverized and stored in clean vials. The known weight of the dried meat powder was digested with 70% HNO<sub>3</sub> and 30% perchloric acid. Residue obtained was treated with HCl and dissolved in distilled water.

#### **2.4.8.3. Mangrove Leaves Samples:**

Mature average sized leaves were hand plucked randomly from different mangrove species such as *Rhizophora mucronata*, *Avicennia marina*, and *Acanthus ilicifolius* were collected seasonally (monsoon, post-monsoon and pre-monsoon) from St-1 and St-2. The leaves were washed thoroughly to remove adhering debris and dried to a constant weight at 80 °C. The dried leaves powdered and one gram of this was digested with HNO<sub>3</sub>, perchloric acid and concentrated HCl. The residue was dissolved in 100 ml distilled water.

In all the above cases (water, oyster and plant samples) triplicate sub-samples were analyzed by using Atomic Absorption Spectrophotometer (AAS), model Shimadzo A6300, feed with Shimadzu auto sampler (ASC-600), to estimate the concentration of various trace metals (iron, manganese, lead, nickel, zinc and chromium), and result values were

expressed on average basis in ppm. Standards were also treated in the similar way.

#### **2.4.8.4. Concentration Factor:**

The concentration factor of the oyster for various metals was calculated by dividing the concentration of the particular metal in the oyster sample by the concentration of the same metal in the ambient sea water as suggested by Kureishy *et al.*, 1981, using the following formula:

$$\text{Concentration Factor} = \frac{\text{Concentration in Oyster Sample}}{\text{Concentration in water Sample}}$$

Generally, all glass wares and plastic devices used in the manipulation of the samples were completely acid washed. All the reagents used in analyzing the above parameters were of AR grade.

An attempt was made to develop a correlation matrix between the different parameters using some statistical analysis described in Townend (2002) and Zar (2006).