CHAPTER 8

SUMMARY AND CONCLUSIONS
SUMMARY

The coastal ocean represents an area of transition where land, air and sea interact to form a wide variety of diverse habitats and ecosystems viz. In the coastal ocean, estuaries are regarded as complex ecosystems, involving interactions of physical and bio-geochemical processes both spatially and temporally. They are the most productive ecosystems in the world and act as conduits for dissolved and particulate effluents discharged from centers of population, industries and from land drainage to the adjacent coastal environment. While some components are consumed or retained within the estuarine environment, rest of it are transported into the adjoining coastal waters. The coastal ecosystems are also places of hectic human activity, resulting in interference due to rapid development.

Estuaries, as the transition zones of the world’s fresh and marine waters, rank on a landscape scale among the most prominent ecotones on earth. Rapid changes and steep gradients of environmental factors, particularly salinity are the hallmarks of these systems (Schlacher and Wooldridge, 1996). These factors and other biological features of the transition zone between the sea and the freshwater have long attracted the interest of marine biologists. Identifying the factors and important processes governing population size and the structure of communities is a central problem in ecology.

One of the aims of benthic ecologist is to understand the ecological processes which is achieved by examining the interrelationship between environmental parameters and benthic community structure (Holland et al.,
1987), anthropogenic impacts (Frouin, 2000) and modelling of the ecosystem (Longhurst, 1978). A better management of living resources in estuaries can be achieved by understanding the ecological processes. Estuaries form an ideal ecosystem in which to observe such interactions due to their wide range of environmental parameters especially salinity and sediment properties (Jones et al., 1990).

Benthic invertebrates are used extensively as indicators of estuarine environmental status and trends because numerous studies have demonstrated that benthos respond predictably to many kinds of natural and anthropogenic stress (Pearson and Rosenberg, 1978; Dauer, 1993; Tapp et al., 1993; Wilson and Jeffrey, 1994). Many characteristics of benthic assemblages make them useful indicators (Bilyard, 1987), the most important of which are related to their exposure to stress and the diversity of their response. Organic wastes such as sewage when introduced into the environment may cause changes in the enclosed bays and estuaries (Bozzini, 1975). Monitoring benthic assemblages in such areas is essential to understand complex ecosystems such as those in estuaries, because it provides a mechanism to view community response to disturbance, gives insight about food resource availability and food-web interactions and may be useful for assessing differences in ecosystem structure and function over space and time.

Benthic organisms continuously restructure or bring about mixing of the sediments by means of locomotion, ingestion, ejection and respiration. This process of mixing the sediment grains is referred to as “bioturbation” and is
recognised as one of the major processes altering the primary structure of sedimentary deposits on millimeter to meter scales. These benthic organisms, play an important functional role in estuaries and other aquatic ecosystems. They alter geochemical conditions at the sediment-water interface, promote decomposition and nutrient recycling, and transfer energy to other food web components (Rhoads, 1974; Boesch et al., 1976; Aller, 1982; Tenore et al., 1984; Schaffner et al., 1987). Benthic community trophic structure is a potentially valuable criterion for integrating and assessing ecological responses along estuarine gradients (Brown et al., 2000).

Ecological studies have a wide range of applications. To begin with, any ecological study based on spatial and temporal variations will give us a baseline data of that particular area under study. Secondly, this baseline data can be useful in comparing with earlier data, if any, from the same area and thus helps in assessing the changes that have occurred over the time scale. Knowledge of all these is useful in understanding the natural fluctuations and the changes caused by human / anthropogenic impact. In addition, these studies help us in assessing the ecosystem dynamics and energy flow from one trophic level to the other and also in resource management. Finally, with the abiotic and biotic data obtained one can arrive to a model, that can be used in predicting any future ecosystem changes or perturbations.

So far, no work had been carried out on the biochemical composition of the sediments from the sites under study. Also macrobenthic species succession was studied using multivariate techniques. In addition, pollution studies were
carried out along a gradient of organic enrichment to see the effect of sewage on macrobenthic community. Finally, assessment of bioturbation activities was carried out using chlorophyll a as an indicator. Besides these preliminary studies on nutrient flux in laboratory microcosm and estimation of the sediment reworking rate for the soldier crab, *Dotilla myctiroides* were carried out. All these issues mentioned above have not been studied so far from the coastal waters of Goa.

In the framework of the present concern for future global environmental changes, the primary interest was to evaluate the changes in the macrofaunal community structure due to natural and anthropogenic changes in the environment. In addition, benthic organisms bring about changes in the sedimentary environment which further contributes in structuring of benthic communities.

Hence, in this study an attempt was made to collect extensive benthic data together with other physico-chemical parameters in the Mandovi and Zuari estuaries and adjoining coastal waters for a period of one year (1997-1998). Studies pertaining to the above would significantly contribute to the ecological and biogeochemical understanding of the tropical Mandovi-Zuari estuarine system, which is one of the largest riverine networks on the southwest coast of India and which is of major importance to life in Goa.
Six stations – three in Zuari estuary (Z1, Z2 and Z3), two in Mandovi estuary (M1 and M2) and an offshore station A, were selected based on the salinity and sediment characteristics.

OUTLINE OF THE THESIS

The research work presented in the thesis is divided into 7 chapters as described below.

CHAPTER 1:
INTRODUCTION

This chapter gives general information about benthic macroinvertebrates and bioturbation and summarises previous work carried out. The importance of ecological studies is stressed upon. It also gives the objectives of the research/study and also evaluates the importance of these organisms in the marine and estuarine environment. The problems and lacunae are pointed out.

CHAPTER 2:
MATERIALS AND METHODS

In this chapter, the study area is described giving a full account of the geographical features, the climate and the station positions.

The materials and the methods used for the environmental parameters such as grain size, organic carbon, organic nitrogen, chlorophyll-α, proteins, carbohydrates, lipids in the sediment and salinity, pH, temperature, dissolved
Methods used to identify macrofauna estimate, biomass and other environmental parameters like salinity, temperature, dissolved oxygen, BOD5, pH of interstitial water and organic carbon, grain size, chlorophyll a of sediment (as mentioned earlier) have been studied. This was to study the changes in macrofaunal community along enrichment gradient.

Also, methods used to study the vertical trend of chlorophyll-a in the sediment, nutrient flux experiments and sediment reworking rate by Dotilla myctiroides, that were studied to assess bioturbation activities have been discussed in this chapter.

CHAPTER 3:
THE ENVIRONMENT

This chapter highlights the hydrological and the sediment parameters analysed.

A total of 13 parameters were studied on the water and sediment samples. Over an annual cycle the mean temperature was seen to be 29.04°C, mean salinity 12.77 psu, mean dissolved oxygen 5.06 ml/l and mean pH 6.89 for the
water samples. Whereas for the sediment, mean value for chlorophyll a was 0.92 μg/g, mean grain size was 2.07 mm, mean sediment sorting coefficient was 0.24φ, mean total organic carbon was 2759.30 mg/g, mean total nitrogen 334.11, mean protein was 8.57 μg/g, mean carbohydrates was 355.95 μg/g and mean lipids was 117.27 μg/g. The mean for the carbon : biopolymeric fraction (C:BPF) was calculated to be 236.1. All these 13 parameters showed significant difference between sites and seasons. Environmental data were closely related to the monsoon behaviour in this region.

CHAPTER 4:
COMMUNITY STRUCTURE

This chapter deals with the study of the community structure. This involves estimating the species density, diversity, evenness, richness, dominance, biomass estimation and species numbers. All these aspects have been highlighted in this chapter along with studying the species succession. Also description of the families of different faunal groups studied is given along with the faunal list.

There was significant difference in population distribution by seasons and not by sites. The population was significantly higher during premonsoon than the other seasons. This change was largely due to seasonality and site position in the estuaries.

A total of 67 species was recorded of which 18 were new to the locality. Polychaetes formed the dominant taxa followed by molluscs and crustacea.
Significantly high biomass was observed at the site with sandy substratum, which indicated moderately sorted low-energy site with relatively intermediate organic carbon and salinity. Significant high species diversity was observed at site having a muddy substratum, indicating a moderately sorted low-energy site, with a relatively high organic carbon and high salinity. Well sorted sediments offer small range of grain sizes and interstitial spaces and thus provide fewer niches and hence contain less diverse fauna (Nichols, 1970; Grebmeir et al., 1989), which agrees with our observation and supports earlier work done (Coleman et al., 1997). Finer sediments supported high species diversity corroborating with earlier findings (Mountford et al., 1997). The fauna comprised of 26 species of polychaetes belonging to 15 families, 15 species of bivalves belonging to 9 different families, 4 species of gastropods belonging to 4 families, 13 species of amphipods and several other groups. All the families have been described in this chapter.

The tropical estuarine soft-bottom species succession varied both temporally and spatially and showed three distinct seasonalities. This dynamic process was mainly influenced by the southwest monsoon and the local biotic and abiotic factors at specific sites. The species succession observed here largely support the models put forth by Clement (1916), Connel and Slayter (1977) and Rhoads and Boyer (1982).

Comparison of the present data with that reported earlier (Parulekar et al., indicates that the general trend in the abundance and biomass of fauna has changed considerably. Changes in macrofaunal community structure can occur
due to change in salinity as a result of monsoon, sediment scouring and colonisation of adults and juveniles of various species.

CHAPTER 5:
INFLUENCE OF ENVIRONMENTAL PARAMETERS ON THE BENTHIC COMMUNITY STRUCTURE

This chapter highlights study carried to test the hypothesis that salinity and sediment properties significantly affect the soft bottom benthic community structure.

For this, the benthic and environmental data was subjected to various statistical techniques. ANOVA and interaction study revealed that salinity and sediment properties (percentage of sand, silt and clay, mean grain size, sediment sorting, organic carbon and chlorophyll a) were the main parameters that influenced the differences in community structure between seasons and sites. Multiple regression analyses indicate that a combination of sediment properties (mean grain size, sediment sorting, percent sand, silt and clay and organic carbon) and bottom water characteristics were the significant parameters explaining 61 - 88% of the variation in the estimate of species diversity at sites A, M1, Z2 and Z3.
CHAPTER 6:
EFFECT OF ORGANIC ENRICHMENT ON THE MACROFAUNAL COMMUNITY STRUCTURE

In this chapter the effects of organic enrichment from a sewage disposal site on the macrobenthic invertebrates is emphasised. Techniques such as Pearson-Rosenberg Model (PRM), abundance biomass comparison (ABC) curve, benthic community structure indices and cluster analysis were used to discriminate and diagnose the pollution gradient.

In the present study, the faunal numbers and biomass at the disposal point was maximum with less number of species. As we moved away from this point the diversity increased but density fell. Also, the fauna comprised mainly the deposit feeder *Capitella capitata* (90 – 95%), indicating organic enrichment of the area. Away from this site, *Capitella capitata* numbers decreased and bivalves which are filter-feeders were seen. The most abundant of them was *Tellina ala*. The species abundance biomass curve (SAB curve) was in agreement with the Pearson-Rosenberg Model as suggested by Pearson and Rosenberg (1978). Abundance and Biomass comparison curves closely coincided and crossed each other at the sewage disposal site indicating moderate organic pollution. Also cluster classification revealed two clusters – one of the polluted site and the other of the non-polluted sites.
CHAPTER 7:

ASSESSMENT OF BIOTURBATION ACTIVITIES

This chapter deals with the assessment of bioturbation activities which the benthic organisms bring about in the sedimentary environment. For this, chlorophyll-a trend in the sediment core was seen, sediment reworking rate by Dotilla myctiroides was calculated and nutrient flux experiments were carried out. Relatively on most of the occasions higher chlorophyll a values were observed on the top layer of the sediment core (0-2 cm) and high pigment values were observed from post to premonsoon. Chlorophyll a profile did not exhibit an exponential decrease with depth as expected. However, irregular profiles of chlorophyll-a observed may be caused by variable seasonal input, temperature dependant activities and mixing by benthic organisms. The reworking rate showed significant positive correlation with the carapace length. The sediment reworking rate works out to be 675.28 g/h/m². Thus population of such species may transport enormous quantity of particles over the surface and hence alter the structural and geotechnical characteristics of the substratum. Microcosm experiments in the laboratory showed increase of nutrient value in the sediment-overlying waters in bioturbated aquarium tanks with crabs than in non-bioturbated aquarium tanks without the crabs. High nutrient values are largely due to sediment reworking and defecation by the crabs and addition of diet in the tanks as their feed. However these are only preliminary studies and more work needs to be carried out in order to firmly establish the facts.
CONCLUSIONS

- Food Index or the ratio of carbon of the biopolymeric fraction to the total organic carbon (C-BPF:TOC), which forms food for the benthic organisms, was calculated for the first time in these estuaries. High Food Index at site M1 supported high benthic diversity and productivity.

- A total of 67 species were identified from the study sites.

- Of the total species recorded, 18 were new to the locality.

- Fauna was dominated by polychaetes (Prionospio pinnata and Clymene annandalei), mollusc (Meretrix casta) and crustacean (Urothoe platydactyla).

- Comparison with benthic data recorded 25 years earlier, showed a clear decrease in the macrofaunal density, biomass and species number, mainly due to mining activities.

- Seasonality of species succession was seen largely due to southwest monsoon.

- 13 environmental parameters were studied. Salinity, dissolved oxygen and total organic nitrogen were the major significant factors that influenced the species diversity, biomass and population.

- Species Abundance Biomass (SAB) curves obtained from the study were in agreement with the Pearson Rosenberg Model.

- Abundance and Biomass Comparison (ABC) curves obtained closely coincided and crossed each other at the sewage disposal site indicating moderate organic pollution.
- Vertical profile of chlorophyll a indicated bioturbation activities.
- Sediment reworking by the crab *Dotilla myctiroides*, in the tanks, enhanced the nutrient flux to the water column.