DIVERSITY AND TROPHIC RELATIONSHIP IN THE INDIAN COASTAL ECOSYSTEM IN RELATION TO MESOZOOPLANTON

Thesis submitted for the degree of

DOCTOR OF PHILOSOPHY

in

MARINE SCIENCE

to the

GOA UNIVERSITY

by

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Dona Paula 403 004 Goa

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Siddhi Ramesh PrabhuKonkar (M.Sc)

Under the Guidance of

Dr C T Achuthankutty

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DEDICATED TO MY PARENTS & BROTHER

CERTIFICATE

This is to certify that the thesis entitled **"DIVERSITY AND TROPHIC RELATIONSHIP IN THE INDIAN COASTAL ECOSYSTEM IN RELATION TO MESOZOOPLANKTON"**, submitted by **Ms. SIDDHI** for the award of the degree of Doctor of Philosophy in Marine Science is based on her original studies carried out by her under my supervision, for the partial fulfillment of the award of the Doctor of Philosophy Degree of the Marine Science during the academic session 2007-2008.

Signature of Guide

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All suggestions made by examiners are incorporated.

9/9/08

DECLARATION

As required under the University ordinance 0.19.8 (vi), I state that the present thesis entitled **" DIVERSITY AND TROPHIC RELATIONSHIP IN THE INDIAN COASTAL ECOSYSTEM IN RELATION TO MESOZOOPLANKTON"** is an original research work carried out by me at National Institute of Oceanography, Dona Paula, Goa, and that no part there of has been published or submitted in part or in full, for any other degree or diploma in any University or Institute. The present study is the first comprehensive work of its kind from the east and west coast of India.

Siddhi Ramesh PrabhuKonkar

Dona Paula, Goa

CONTENTS

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PREFACE

Plankton is a community of both plants and animals whose power of locomotion is insufficient to prevent them from being passively transported by currents. Plankton are primarily divided into three broad functional groups (trophic level) viz, (1) Phytoplankton- autotrophic that live in the upper water column where there is sufficient light to support photosynthesis (2) Zooplankton- small protozoan or metazoans that feed on other plankton which also include the eggs and larvae of larger animals, such as fish, crustaceans, and annelids, and (3) Bacterioplankton- bacteria and archaea, which play an important role in rematerializing organic material down the water column.

Zooplankton consists of a diverse group of organisms that vary greatly in size and shape, ranging from millimeter sized crustaceans to jellyfish larger than a meter in diameter. Zooplankton plays an important role in many pelagic ecosystems. They are important grazers of phytoplankton and form a significant portion of the diet of many larval and juvenile fish. Zooplankton being a major link in the energy transfer in the secondary level, plays a significant role in the productivity potential of any aquatic environment. In short, an estimate of zooplankton standing stock provides an index to the fertility of the sea. The field of zooplankton ecology involves studying the trophic relationship between zooplankton and the physical and biological factors that are affecting them or influenced by them.

Zooplankton is classified into several groups by size. Mesozooplankton are the heterotrophic organisms and are median sized group (size range: 200μm-2 cms). They include metazoans varying in size from rotifers and copepod nauplii to large cnidarians. They are ubiquitous and occur in fresh water to marine habitat. They transform energy from phytoplankton to microzooplankton into higher trophic level.

Apart from the understanding of phytoplankton and microzooplankton, the attempt to ensue the phase of mesozooplankton in trophic relationship is poorly reviewed. The study on mesozooplankton from the west and east coasts of Indian Peninsula in this thesis is the first attempt from the Indian Ocean.

Indian Peninsula divides the Northern Indian Ocean into the Arabian Sea and the Bay of Bengal. It is the most untypical area among the world oceans with Bay of Bengal experiencing the annual reversal of monsoon and the Arabian Sea particularly intriguing with its mysteries only unfolding. According to the different physical and chemical condition, the near shore and estuaries that influence the diversity, distribution and performance in the food web at both sides of the Indian coast follow their own unit pattern.

The present investigation is an attempt to provide new data base of interest on the mesozooplankton related to the food web, by determining the diversity, distribution and abundance in near shore and off shore regions of the east and west coasts of India in relation to physical, chemical and biological parameters.

List of Tables

List of Figures

CHAPTER 1:

Introduction

1.1 Characteristics of mesozooplankton

Ocean is known as the 'last frontier' or 'saviour of mankind' because it covers 71% of the total earth's surface and is a reservoir of all the resources that the mankind needs, both living and non-living. Plankton is a community including both plants and animals that consists of organisms which are at the mercy of currents . The name plankton is derived from the Greek word πλανκτος ("planktos"), which means "wanderer" or "drifter" (Thurman, 1997). Some forms of the plankton are capable of independent movement and swim up to several hundreds of metres vertically in a single day. This behaviour is known as diel vertical migration and their horizontal position is determined by the currents in water body which they inhabit. Organisms classified as "plankton" are unable to resist the ocean currents while the nektonic organisms can swim against the ambient flow of the water and control their position (such as squid, fish, krill and marine mammals).

Depending on the length of planktonic life, planktonic organisms are classified into 'Holoplankton', that spend their entire life cycle as plankton (eg., most algae, copepods, salps, jellyfish, etc.). and 'Meroplankton' that are planktonic only for the early part of their lives (e.g., larval stages of fish, prawn, crabs, squids, barnacles, etc.), and become either nekton (eg., pelagic fishes, squids, etc.) or adapt benthic (larvae of sea urchins, prawns, crabs, marine worms etc.) or sessile existence (e.g., barnacles, mussels, oysters etc.). Abundance and distribution of plankton are strongly dependent on factors such as ambient nutrients concentration, physical state of the water column and abundance of other plankton.

Plankton are primarily divided into three broad functional groups (trophic level).

(1) Phytoplankton- autotrophic pro- or eukaryotic algae that live in the upper water column where there is sufficient light to support photosynthesis and thus form the lowest level in the

food chain. They have the capability to photosynthesis using sunlight, carbon dioxide and inorganic nutrients available in the water column. Chlorophylls are the principle photosynthetic pigments of the plant kingdom, converting light energy to chemical energy via the process of photosynthesis. Therefore, they are known as the primary producers. These floating microscopic marine plant populations have a truly global distribution and contribute over a quarter of the total vegetation of the planet. The tens of thousands of species present a variety of forms, and even surpassing, those of terrestrial plants. Cyanobacteria, diatoms and dinoflagellates form the major components of this group.

(2) Zooplankton- These are the microscopic floating animals which occupy the secondary level in the food chain and are known as the secondary producers. The herbivorous zooplankton graze on the phytoplankton and convert the plant biomass into animal biomass, thus transferring the energy available at the primary trophic level to the secondary trophic level. The larger zooplankton, which are either omnivores or carnivores, feed on the herbivores. The zooplankton biomass thus produced at the secondary level forms the main source of food for the next trophic level, known as the tertiary level.

The nekton, including the pelagic fishes consume the zooplankton (some like oil sardines feed on phytoplankton also) and transfer the energy available at the secondary trophic level to the tertiary trophic level.

(3) Bacterioplankton- bacteria and archaea, play an important role in remineralising organic material at the bottom of the water column. The dead and unused phytoplankton and zooplankton sink to the bottom as organic detritus. As it descends, the detrital matter is consumed by the detritivores (e.g., salps, doliolids, etc.) and the remaining aggregate at the bottom and add to the detrital pool. This unused organic matter forms the substrate for microbial population, particularly bacteria and they re-mineralize the complex organic

molecules into inorganic nutrients such as phosphate, nitrate and silicate, which are essential for photosynthesis. The organic matter that is deposited at the bottom also forms a rich source of food for the bottom dwelling organisms known as the benthic fauna which also occupy the tertiary trophic level. This scheme divides the plankton community broadly into the three groups, viz. producer, consumer and recycler. In reality, even the trophic level of some plankton is not straightforward. For example, although most dinoflagellates are either photosynthetic producers or heterotrophic consumers, many species are also mixotrophic, depending upon the circumstances prevailing around them.

Plankton are found throughout the oceans, seas and lakes. However, the local abundance of plankton varies horizontally, vertically and seasonally. The primary source of this variability is the availability of light. All planktonic ecosystems are driven by the input of solar energy and this confines primary production to the upper surface layers, and to geographical regions and seasons when light is abundant. A secondary source of variability is that of nutrient availability. Although large areas of the tropical and sub-tropical oceans have abundant light, they experience relatively low primary production because of the poor availability of nutrients such as nitrate, phosphate and silicate. This is a product of large-scale ocean circulation and stratification of the water column. In such regions, primary production, usually occurs even at greater depth, although at reduced level due to reduced light penetration.

Plankton are divided into seven categories and mesozooplankton is the median sized group. (size range: 200 μm - 2 cm).

- Megaplankton - 20-200 cm
- Macroplankton - 2-20 cm
- Mesoplankton - 0.2 mm-2 cm

- Microplankton - 20-200 μm
- Nanoplankton - 2-20 μm
- Picoplankton - 0.2-2 μm (mostly bacteria)
- Femtoplankton - < 0.2 μm (consisting of marine viruses)

However, some of these terms may be used with very different boundaries, especially on the larger end of the scale. The existence and importance of nano- and even smaller plankton was only discovered during 1980s, but they are thought to make up the largest proportion of all plankton in number and diversity.

Zooplankton serves as a food to many fishes, especially to juveniles of most of the pelagic fishes. Therefore, the measurement of the zooplankton production is an important step in the evaluation of an ecosystem. They inhabit the aquatic ecosystem at almost all depths, and occupy practically every type of ecological niche, but significantly with less density at deep sea. Majority of zooplankton are confined to the photic zone, mainly due to food availability (phytoplankton). They form an intermediary part in the marine food chain as the secondary producer, transferring energy from primary trophic level to tertiary trophic level.

Energy transfer from phytoplankton to zooplankton and to higher trophic levels normally occurs through the conventional food chain. However in situations where phytoplankton productivity is low the microbial loop becomes active, and the zooplankton survive grazing on them. Microzooplankton, bacteria etc. serve as food for the mesozooplankton when the primary productivity is low, as seen in the Arabian Sea (Madhupratap, et. at., 1996). The organic matter derived from the plankton is utilised by bacteria and they in turn, are consumed by the hetero-flagellates, which are subsequently consumed by the micro-zooplankton. The micro-zooplankton then forms the major source of food for the larger zooplankton (Fig. 1).

Trophic levels can be expressed in terms of energy transfer. When an animal eats part of that energy is used to fuel respiration, low motion etc., and goes off as heat. The remainder is fixed as an increase in biomass, either through individual growth, or reproduction. The efficiency with which the biomass of one trophic level is transferred to the biomass of the next higher trophic level is known as the transfer efficiency. The transfer efficiency of phytoplankton to zooplankton is roughly 20%. The transfer efficiency of primary consumers to secondary consumers is roughly 10-15%. The average transfer efficiency from the primary producer to the top level predator in a food chain tends to be around 10%. This means that for each successive trophic level, there is about 80 - 90% energy loss through respiration and low motion. One consequence of this is that the food chain can only afford to be a few trophic levels in length, because the top level predators have only a small percentage of the original phytoplankton biomass available to them for food.

The coastal zone is a highly dynamic, eco-sensitive and productive area. Zooplankton is considered to be the ecological indicators of water bodies. Any change in distribution pattern of zooplankton in the coastal area is considered to be indicative of a particular phenomenon, which is responsible for such alteration in the production potential of the area. They play an intermediate role between the primary producers and the carnivores in the aquatic environment and transfer the organic energy to higher trophic level. They includes herbivores, carnivores, omnivores and detrivores thus, forming an efficient taxa in utilization of biotope and energy transfer (Goswami and Padmawati, 1996). They have significant role to play in the biological cycling of carbon and other elements in the ocean. Variability and patchiness are unique features in zooplankton distribution (Nair, et. al., 1981). Even diurnal vertical migration is a fascinating instance of behavioural patchiness which greatly helps in the transportation of organic matter and nutrients between different water layers that promotes regeneration of nutrients.

The west coast contributes substantially to India's total marine fish landing, compared to the east coast. The success or failure of this fishery largely depends upon the availability of plankton (Padmawati and Goswami, 1996 a). It has been reported that the peak fishing season coincides with the zooplankton abundance and the fishes directly feed on them (Neelam, et. al., 1998; Nair, 1977).

Zooplankton also play an important role in the lagoon and coral reef ecosystems. They serve as a food source for corals and innumerable invertebrates and fishes that inhabit the coral ecosystem. Zooplankton is highly influenced by various environmental factors viz. currents, tides, vertical turbulent mixing (Nasser, et. al., 1998), availability of food, nutrients, high surface temperature, dissolved oxygen, salinity, solar radiation, prey-predator relationships, low production of phytoplankton (Padmawati and Goswami, 1996 b), seasons, depths and hydrographic condition as well as environmental stress due to anthropogenic pollutants or any other man-made modification in the environment (Nair, et. al., 1981 b).

Mesozooplankton are the major consumers of phytoplankton, and have a significant impact on the oceanic biogeochemical cycles of carbon and other elements. Their contribution to vertical particle flux is much larger than that of microzooplankton, yet most global biogeochemical models have clubbed these two plankton functional types together.

1.2 Importance of mesozooplankton

Zooplankton serve as an important trophic link in the marine food chain as it transfers energy from primary producers to tertiary producers. Zooplankton chiefly consume the primary producer (phytoplankton) and form the major food sources for tertiary producers. In other words, zooplankton convert plant organic matter into animal organic matter and supply to higher trophic level. Therefore they play an important part in determining the fishery potential of any region. Although most of the species of zooplankton are beneficial to the fisheries a few, however, are detrimental since they prey on them. For instance, jelly fishes, arrow warms and other larger zooplanktons voraciously feed on the fish larvae, decimating the fish population.

1.3. Literature Review

Hansen, (1887) coined the word plankton for the aquatic community. Sewell, (1928, 1929) made a general survery of plankton in the Bay of Bengal and the Arabian Sea. Work of Hornell and Nayudu, (1923) was the first on plankton of the coastal waters of India. By virtue of the sheer abundance and the role in the energy transfer from primary to tertiary trophic level i.e. phytoplankton to nekton, they are considered as the chief index of utilization of the aquatic biotope at the secondary trophic level (Santhakumari & Peter, 1993).

Tropical coastal zooplankton community has been employed in identification of water quality and also as an index of eutrophication (Youngbluth, 1976). Madhupratap and Onbe, (1986) opined that low plankton diversity is an index of poor and deteriorating water quality. Zooplankton distribution is a bio-hydrographical feature governed mainly by temperature and salinity (Villate, et. al., 1997). It has been shown by Achuthankutty, et. al., (1998) that in tropical estuaries the mesoplankton organisms tend to move to the coastal waters to tide over the environmental extremities, particularly the low salinity prevailing during the monsoon season. They have also demonstrated that some species of euryhaline copepods migrate to the coastal waters when the salinity is conducive for their growth and move back to the estuary when the salinity improves.

Upwelling leads to increase in nutrients resulting in increased phytoplankton standing stock in the coastal waters of the west coast of India (Madhupratap, et. al., 1990) and as a consequence, the zooplankton biomass also increases (Haridas, et. al., 1980), suggesting that sequential community development occurs subsequent to the commencement of upwelling. They also observed that zooplankton avoid low oxygen bottom waters caused due to upwelling resulting in accumulation in the upper mixed layers.

It is an established fact that phytoplanktonic organisms reduce the surface nutrients and high values are recorded when replenishment becomes active. This replenishment occurs by (i) run-off from the river mouths and/or land run-off during rainy season and (ii) seasonal coastal upwelling. The seasonal upwelling observed by La Fond, (1954), La Fond & Sastry, (1957) in the central part of the east coast of India has been contradicted by Jayaraman, (1965). But metereological conditions like heavy winds and cyclones play an important role in the vertical mixing of nutrients in the shallow northern part of the Bay. The incidence of storms in the Bay of Bengal is, on an average 4 to 5 times more than that over the Arabian Sea (Subrahmanyam, 1978). These factors must have contributed to the fertility of the sea near the head of the Bay and the concentrations of silicates, phosphates and nitrates are therefore higher than those recorded off Waltair, Madras, and Mandapam on the east coast of India. In contrast with the extremely variable salinity, the temperature is more or less uniform in the region .The highest surface temperature in May occurs when the sun is directly overhead with maximum incoming radiation. The second maximum in September may be interpreted in terms of monsoon reversal and the weak wind at the retreat of the south west monsoon.

Upwelling along the west coast more pronounced. Coastal upwelling associated with the southwest monsoon along the west coast of India (Banse, 1959, 1968); Ramamirtham and Jayaraman, (1960) is responsible for nutrient enrichment of surface layers and increasing the biological productivity compared to the other seasons and non-upwelling areas (Madhupratap, et. al., 1990). The upwelling creates a nutrient rich environment which enhances phytoplankton growth, resulting in increased zooplankton abundance specially herbivorous (Sankaranarayanan and Jayaraman, 1972; Devassy, et. al., 1983. In the Arabian Sea apart from the coastal upwelling, open ocean upwelling and lateral advection of nutrients lead to fairly high primary production.

The relative richness of species in comparable samples can be good indicator of environmental health (Costello, 1998). Detectable changes in the abundance and/or species composition of mesozooplankton may be a reflection of the changes that is taking place in the ocean environment, affecting the phytoplankton population and since zooplankton are consumed by larger animals (some of which are of commercial importance), changes in zooplankton communities can provide early indications of the imminent changes in the food conditions (Clark, 1992). He further adds that because many zooplankton are relatively short-lived and are capable of high growth rates, they respond quickly to environmental perturbations that influence the diversity.

The mesozooplankton abundance, distribution and productivity in the Indian coastal waters are influenced by many factors, particularly the monsoons, upwelling, current reversals, oxygen depletion, salinity stratification, phytoplankton bloom etc.

The proposed study is an attempt in understanding the role of environmental factors on the distribution and abundance of mesozooplankton in the coastal ecosystem so as to identify the key parameters and also to find out the interactions between the different trophic levels.

Several studies have indicated that ambient chemical conditions and physical changes in water are responsible for the temporal distribution of zooplankton (Madhupratap and Haridas, 1975; Sarkar, et. al., 1986; and Madhupratap, 1987). Environmental parameters like salinity, dissolved oxygen, BOD, tides, circulation, currents besides predation, competition, size and external morphology are known to play a significant role in determining the quality, quantity and diversity of zooplankton in the estuaries and coastal waters. (Santhanam and Srinivasan, 1994). Zooplankton also show uneven distribution as they occur in patches over spatial scales from meters to kilometers and on temporal scales from diel through seasonal and annual.

Lindeman, (1942) developed the classic concept of community dynamics. There were different studies for measuring the rate of energy transfer or the trophic efficiencies in different aquatic ecosystems (Smith, 1982; Park and Marshall, 2000; Madhupratap and Onbe, 1986; Villate, 1994; Parchuk and Klochenko, 1994; Kouwenberg, 1994; Nair, et. al., 1983). Twombly, (1994) studied environmental factors that determine distribution of species of zooplankton. Zooplankton forms the largest ecological group by virtue of their abundance and intermediary role between phytoplankton and fish. Godhantaraman and Krishnamurthy, (1997) have studied prey-predfator inter-relationship in tropical microzooplankton. Gaard, (1999) studied zooplankton community structure in relation to biologial and physical environment. Zooplankton is considered as the chief index of utilization of aquatic biotope at the secondary trophic level (Dhawan, 1972, Govindan, et. al., 1982). Mackas and Anderson, (1986) studied community variability in Columbia fJord system. Glover, (1979) studied natural fluctuations of population of zooplankton. Balachandran, (1973a) reviewed causes of deterioration in zooplankton samples. Subsequent studies on zooplankton methodology were carried by Tranter, (1973), Frangou, (1996), Frangou, et. al., (1998).

Wiafe and Frid, (1996) have studied the importance of zooplankton in relation to physical and biological mechanisms. Nord, (1983) has studied qualitative and quantitative variation of zooplankton in relation to climatic changes. Cooley, et. al., (1986) have studied zooplankton dynamics in relation to phosphorous loading. Modenutti, (1987); Moraitou, (1976); Pavlova and Kuftarkova, (1995); Frangou and Papathanassiou, (1991) have studied zooplankton in relation to pollution. Park and Marshall, (2000) have studied community structure and trophic gradient. Frangou, et. al., (1995) have looked into the differentiation of zooplankton community in two different areas, viz the west and east coast. Mullin, (1966) has studied selected feeding by calanoid copepods from the Indian Ocean. Roff, et. al., (1995) have studied bacteriovory by tropical nauplii.

Zooplankton studies from the Indian Ocean received impetus during the International Indian Ocean expedition (1960-65). The data collected gave a generalized picture of distribution of zooplankton biomass. Studies carried out by Mathew, et. al., (1989) have carried out studies on zooplankton biomass, secondary and tertiary production in the EEZ of India. However, compared to the west coast, our understanding on zooplankton along the east coast is limited (Achuthankutty, et. al., 1980; Krishnakumari and Goswami, 1993; Antony, et. al., 1997; Madhupratap, et. al., 1981a). Information on zooplankton from the Bay of Bengal is available from the studies of Sarkar, et. al., (1986); Nair, et. al., (1977), Nair, et. al., (1980); Prasad, (1969); Stephen, (1984). Sastry and Chandramohan, (1995) have studied zooplankton of the Godavari estuary and that of Tamil Nadu coast is studied by Santhakumari and Saraswathy, (1981) and Mishra and Panigrahi, (1999). Copepods in Andaman and Nicobar were examined by Madhupratap, et. al., (1981 a & b) Goswami and Rao, (1981) and Mathew, et. al., (1996); while chaetognaths were studied by Nair, et. al., (1981 a).

Compared to the east coast, the west coast of India has been more extensively investigated resulting in a large number of publications on zooplankton ecology. In the Lakhadeweep waters studies on zooplankton have been carried out by Madhupratap, et. al., (1991 a & b), Achuthankutty, et. al., (1989), Goswami, (1973), Nasser, et. al., (1998), Thompson, (1990), Goswami, (1979 a & b). Extensive work on zooplankton has been done long the south-west coast (Cochin backwaters and coastal waters) (Madhupratap and Haridas, 1975; Wellershaus, 1969; Srinivasan and Santhanam, 1991; Stephen and Iyer, 1979; Thompson, 1991; Santhakumari and Peter, 1993; Haridas, et. al., 1973; Madhupratap, 1978, 1980, 1981; Nair, 1980-81, Madhupratap and Haridas, (1978). Smith, (1982) studied distribution, abundance and feeding of zooplankton in the northwest Indian Ocean. Sumitra-Vijayaraghavan, et. al., (1982) have studied zooplankton from the Arabian Sea of south central west coast of India. Haridas, et. al., (1973) have studied zooplankton biomass with chemical parameters in the backwaters of Cochin. Santhakumari, (1991) has studied standing stock and community structure along Karnataka coast.

Along the off Goa coast, major studies on zooplankton were carried out by Achuthankutty, et. al., (1998); Nair and Selvakumar, (1979); Nair, (1980); Nair, et. al., (1983); Padmavati and Goswami, (1996 a & b); Goswami, (1985 a & b), Goswami, (1996); Goswami, et. al., (1979). Goswami and Devassy, (1991); Goswami and Padmavati, (1996); Pant, et. al., (1984); Selvakumar, et. al., (1980, 1986). Verlencar, (1987) has studied the distribution of phosphate and nitrate in relation to primary production in the coastal and estuarine waters of Goa.

Noble, (1968) carried out detailed studies on temperature, salinity, pH and dissolved oxygen in relation to occurrence of upwelling in the Arabian Sea and Bay of Bengal. Sastry and Gopinathan, (1985) observed fluctuations in the phosphate content influenced by the monsoon in coastal waters of Arabian Sea. Menon and George, (1977) recorded spatial and temporal variations in the salinity and nutrients influenced by the monsoon season. Segar, (1982) studied the distribution of nitrate in the Arabian sea. Annigeri, (1968) described the fluctuations of temperature, salinity, dissolved oxygen and nutrients at surface, mid-depth and bottom waters and observed increased concentrations of nutrients with depth in the inshore waters of Karwar Bay. Annigeri, (1972) documented a distinct change in the physico-chemical properties of waters a surface, columnar and bottom of the inshore waters of Karwar, Zingde and Singbal, (1983) reported high concentrations of nutrients during the southwest monsoon in the coastal waters of Binge Bay near Karwar. The monthly and seasonal variations of some hydrographic parameters off Mangalore were described by Suresh and Reddy, (1975), Suresh, et. al., (1978), Benakappa, et. al., (1979) and Reddy, et. al., (1979). Suresh, et. al., (1978) observed the occurrence of upwelling along the coastal waters of Mangalore. Spatial and temporal distribution of phosphate and silicate in the Arabian sea off Mangalore was studied by Manjappa and Gupta, (1988). Lingadhal, et. al., (1998) reported lower concentration of dissolved oxygen, iron, nitrate and phosphate which coincided with higher phytoplankton bloom in the coastal waters of Mangalore. Eknath, (1978) and Murthy, (1982) have documented monthly variations of hydrographical parameters long Thannirbhavi area receiving effluent from a fertilizer factory.

Paulinose, et. al., (1998) observed environmental parameters like salinity, temperature, dissolved oxygen and nutrients in the Gulf of Kutch. Banse, (1990) has reviewed the oceanographic observations off the east coast of India. He observed that river discharge during the south west monsoon could not contribute much to the phosphate of the sea and could not observe seasonal blooms of phytoplankton along Madras coast. Sarma, et. al., (1988) found significant correlation between nitrate and phosphate with planktonic growth in coastal waters of Vishakapatnam along the east coast. Raut, et. al., (2005) and Ganesh & Raman, (2007) have observed high sediment organic load off Kakinada.

The west coast of India is more productive than the east coast both at primary and secondary levels. This is also reflected in the fish landings which are considerably higher from the Arabian Sea than from the Bay of Bengal (Prasad, 1969). Santhakumari, (1991) has studied standing stock and community structure along Karnataka coast. The total living carbon content in the Bay of Bengal is much lower than in the Arabian Sea. (Gauns, et. al., 2005)

1.4. Objectives and Scope

The published work on mesozooplankton related with food web from the Indian waters are limited. Recently, Gauns, (2000) has studied the microzooplankton and its relation with food web from west coast and described the importance of microzooplankton which play a key role in the microbial loop to sustain the mesozooplankton abundance in the absence of a conventional food chain. However, recent studies from west coast (Madhupratap, et. al., 1992, 1996; Gauns, et. al., 1996; Ramaiah, et. al., 1996) strongly indicate that microzooplankton could be the key community for an understanding the food chain of the region.

The present study was carried out in the coastal region of the west coast (Goa and Mangalore coast) and east coast (Kakinada) of India. The study area extends geographically from latitude $15^{0}30'00$ to $73^{0}35'00$ along the Goa coast $13^{0}00'00$ to $74^{0}38'11$ along the Mangalore coast (Fig. 2.1), and $16^{0}43'00$ to $82^{0}33'00$ along the Kakinada coast (Fig. 2.2).

According to different physical and chemical conditions, the near-shore and estuaries influence the diversity, distribution and food web dynamics in both sides of the Indian coasts. Most of the papers published from these areas deal with some ecological aspect, of mesozooplankton, but biological productivity patterns have not been attempted. There were very few published papers which compare the abundance and diversity of mesozooplankton along the east and west coast of India in relation to ecological variations.

The role of mesozooplankton as grazers in performing trophic link between phytoplankton and higher trophic level is not properly understood. Also the ecology and diversity of mesozooplankton from the east and west coasts of India need a comprehensive study. In order to fill these lacunae, the present study was taken on the mesozooplankton from two different environments, Goa and Mangalore coasts (west coast) and Kakinada (east cost). The proposed study is an attempt to understand the role of environmental factors on the distribution and abundance of mesozooplankton in the coastal ecosystem so as to identify the key parameters and also to find out the interactions between the different trophic levels. The study addresses the following main objectives:

1] To study the spatial and temporal variation in the diversity of mesozooplankton in the coastal waters.

2] To understand the eco-biological influence on the distribution, abundance and productivity of mesozooplankton.

3] To evaluate the interactions between different trophic levels in relation to mesozooplankton.

Thus, the present thesis presents the information on the quantitative and qualitative information of the mesozooplankton, including group diversity, seasonal distribution and relation with respect to physical, chemical and other biological parameters in the coastal waters along the west (Goa and Mangalore) and east (Kakinada) coasts of India.

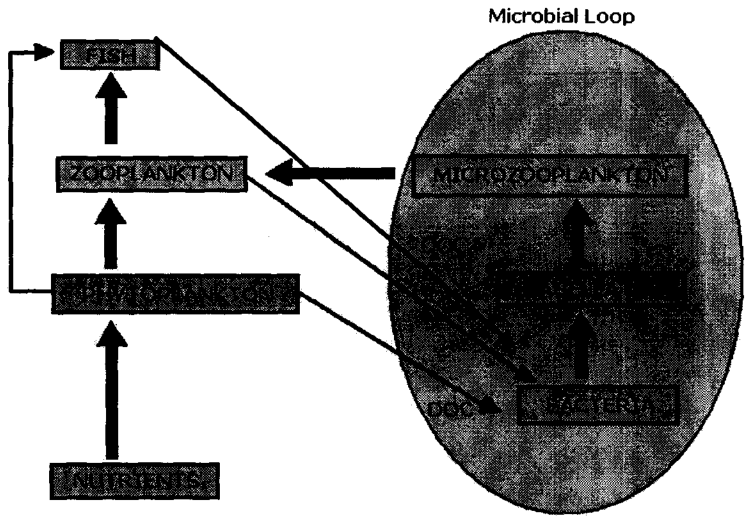


Fig. 1. **Schematic picture of the conventional food web (left) and microbial loop (right)**

CHAPTER 2:

Study Area

2.1 Introduction

To understand the basic physical oceanography of the Indian Ocean (IO) it is necessary to study its geographical setting as well as geomorphology. The setting of the IO is unique as it has no connection with northern polar seas, unlike the Atlantic and the Pacific oceans. With the collapse of the North East winds in March-April, the North East monsoonal circulation also collapses. The South West monsoon picks up in May and everywhere in the northern Indian Ocean and north of the equator, the surface waters flow in an eastward direction. By July the monsoon current is well established north of the equator. At the same time, a north flowing Somali current (SC) is strongly developed as a continuation of the South Equatorial Current. The SC which is considered to be the western boundary is closely associated with strong upwelling along the northern coast of Somalia and the coast of Oman. Anticyclonic circulations are developed in the Arabian Sea and the Bay of Bengal and as a result, a strong southerly current in the west coast of India develops. In the Bay of Bengal, a coastal current moves up the east coast of India as part of the anti-cyclonic gyre and is called the East Indian current. In the central portions of these two large seas, the surface currents are variable. The surface flow of water does not penetrate as deeply during the northeast monsoon as during the southwest monsoon, because of the relatively weaker winds during the northeast monsoon. Between the northeast and southwest monsoons, there exists a transitional period during which the surface circulations are variable north to the equator. The Somali eddy (gyre) generated during the South West monsoon may persist for some time after the cessation of this monsoon (Bruce, et. al., 1981).

North of the equator, peninsular India divides the northern Indian Ocean into two large bays, viz. the Arabian Sea and the Bay of Bengal. Oceanographically they are very different, but both interestingly reflect their physical and chemical features, the influence of the reversing monsoons and the postmonsoon flooding, particularly along the Indian coastal areas. Many large rivers namely , the Irrawaddy, Brahmaputra, Ganges, Mahanadi, Godavari, Krishna and Cauvery debouch into the Bay of Bengal and as a result the salinity of the surface waters is relatively low (30-34) over wide areas. The dilution also contributes to the marked stratification and perhaps, suppression of vertical mixing in the Bay. Since there are no major rivers draining into the Arabian Sea, except the Indus, the salinity is fairly high in the northern part and even more so in the interior areas of the Red Sea and the Persian Gulf, where it ranges from 36 to 40 or even more.

The wind driven processes contribute to the creation of 2 different surface water masses in the northern Indian Ocean. One is the high salinity Arabian Sea water (ASW) and the other, the low salinity Bay of Bengal water (BBW). In the former high salinity is due to excess evaporation over precipitation and in the latter, the low salinity is due to large runoff from the various rivers of the Indian sub-continent. Besides, the high salinity waters of the Red Sea and the Persian Gulf also contribute to the much higher salinity of the Arabian Sea water, compared to the Bay of Bengal water. As a result, ASW has a surface salinity value upto 36.8, whereas the Bay waters show a decline in salinity from about 34 at 5^0N to 31 in the northern part of the Bay. In response to the prevailing winds, the North Equatorial Current which develops north of the equator has appreciable velocities south of Sri Lanka and the Arabian Sea. A branch of this current flows north along the west coast of India, bringing low salinity Bay of Bengal water to the west.

North of the sub-tropical convergence, most of the Indian Ocean is in the tropics and as a result the northern Indian Ocean surface water is tropical in nature, having a uniformly high temperature between 25^0 and 29^0C (Reverdin and Fieux, 1987).

In view of the seasonal reversal of the monsoon winds in the northern Indian Ocean, the direction of the surface is determined mainly by the prevailing winds. The northeast monsoon starts sometime during November and reaches its peak strength during December-February. The northeast winds pick up some moisture as they blow over the Bay of Bengal but, in the absence of high mountain ranges along the east coast of India, precipitation is limited. The feature that differs the Indian Ocean the most from the other two oceans is seasonal (half yearly) reversal of atmosphere and oceanic circulation under the influence of the northeast (NE) and southwest (SW) monsoons. This arises from differential heating and cooling of the land and ocean.

Arabian Sea is bounded by the African and Asian landmasses in the west and the north, the Indian subcontinent and the Maldives Islands chains in the east and the equator in the south. In this region particularly along the Arabian coast, and runoff (except off the west coast of India) where annual precipitation slightly exceeds evaporation and runoff. (Venkateswaran, 1956) This excessive evaporation results in high surface salinities. Together with winter cooling in the north, this leads to the formation of high salinity water masses which sink and renew upper subsurface layers. (Prasanna Kumar and Prasad, 1999; Dietrich, (1973)

The Bay of Bengal, forming the northeast arm of the Indian Ocean is connected to the Pacific Ocean through the Australasian seaways. This basin is also strongly influenced by the monsoonal winds. The enormous quantity of freshwater influx it receives is not associated with significant inputs of inorganic nutrients such as nitrate and phosphate (1.6 x 1012 m^3y^{-1}). (Subrahmanian, 1993; DeSouza, et. al., 1981; Sen Gupta and Naqvi, 1984). Also the turbidity resulting from the high suspended load attenuate light, resulting in shallow euphotic zone in the north and over the shelf (Qasim, 1979).

A large number of cyclonic disturbance in the Bay lead to wind mixing that deepens mixed layer depth (MLD), thereby supplying nutrients and sustaining primary production. Along the east coast of India upwelling has been observed to occur during the southwest monsoon as well as summer inter monsoon seasons, although it is not as intense as in the Arabian Sea. (Shetye, et. al., 1991) The upwelled water seldom reaches the surface because of strong thermohaline stratification. Upwelling also occurs off the east coast of India, particularly alog the southern boundary close to the coast. (La Fond, 1954; Varadachari, 1961; Muraleedharan, et. al., 2007) The main feature of this upwelling is the reduction of sea-surface temperatures by 4-5^{0}C and the development of rich plankton blooms.

The reasons for the BoB being less productive than the AS include the absence of strong upwelling and prevalence of strong thermohaline stratification caused by the inputs of freshwater. The excess of precipitation over evaporation is another source of freshwater (Prasad, 1997). The rivers also add enormous quantities of particulate matter which interacts with the biogenic matter forming dense particles that sink rapidly through the water column into the deep making the Bay a sink for atmospheric carbon dioxide (unlike the eastern Arabian Sea). Even though there is large sinking of organic particles and more bacterial density, the oxygen minimum zone in the Bay of Bengal is not as thick and as intense as in the Arabian Sea. Recent findings of the Arabian Sea biogeochemistry is the occurrence of seasonal hypoxia along the west coast of India (Naqvi, et. al., 2000).

Rao, et. al., (1994) and Naqvi, et. al., (1996), showed that the respiration rates in subsurface waters are also lower in the Bay of Bengal as compared to the Arabian Sea presumably because of ballast effects of the terrigenous matter which causes rapid sinking of organic matter through the water column (Ittekkot, et. al., 1992).

Coastal waters form a multi-dimensional system where the dynamic processes are rarely in equilibrium. Compared to the open ocean systems, the coastal region exhibits environmental gradients occurring spatially and temporally on micro or macro-scale. The study of the chemical and physical aspects of the nearshore environment provides background information necessary for the understanding of the coastal oceanographic processes.

The coastal areas of the Arabian Sea are major zones of upwelling during the southwest monsoon. (Currie, et. al., 1973). Particularly off the Arabian coast, upwelling is observed to extend 400 km offshore and runs parallel to the coast for nearly 1000 km. This area shows the maximum abundance of phytoplankton and zooplankton in the Indian Ocean. Off the southwest coast of India, upwelling starts even before the onset of the southwest monsoon and continues till it ends in September. Major features of the upwelling are the upward displacement of the 20^{0}C isotherm by nearly 100 m and the invasion of the shelf off the west coast by nutrient rich waters. These changes favours the occurrence of very rich zooplankton and enormous shoals of clupeid fishes (particularly sardines and mackerels).

2.2. Study Area

The northern Indian Ocean comprises of the Arabian Sea, the Bay of Bengal and the adjacent areas. The Arabian Sea is bounded by the African and Asian landmasses in the west and north, the Indian subcontinent and the Maldives in the east and the equator in the south. Although the geographical setting is somewhat similar, the hydrographic and hydrochemical characteristics widely differ between the Arabian Sea and the Bay of Bengal. The Arabian Sea receives lower volumes of river runoff as very few major rivers (Tapti and Narmada) empty into it. The winds in the Arabian Sea are dominated by two periods of strong monsoon- southwest (summer) and northeast (winter). During southwest monsoon (June-September), winds are strong and southerly, whereas during northeast monsoon (November-

February), the winds are generally weak and northerly. The transition between these two monsoons is known as the intermonsoon.

The oceanographic processes in the Bay of Bengal are largely influenced by the annual reversing of the monsoon winds. Reversals of monsoon winds also results in reversal of surface circulation, which brings about marked changes in the hydrography of the upper waters. Further, the Bay also receives large volume of fresh water from several large rivers opening into it such as Irrawady, Brahmaputra, Ganges, Godavari and Cauvery, particularly during the southwest monsoon and drastically brings down salinity. Based on the changing winds, seasons of the study region has been classified as the northeast monsoon (November to February) and the southwest monsoon (June - mid September). These seasons are separated by the intervening periods called the spring inter monsoon (April-May) and fall-intermonsoon (mid September-mid November). The study area in the Bay of Bengal, the Krishna-Godavari Basin (KG Basin) is located along the Kakinada coast of Andhra Pradesh. The coastal waters of the Kakinada also experience a seasonal reversal of circulation due to the monsoon winds.

The study site in the Arabian Sea was represented by two areas, one along the Goa coast (into which two estuaries the Mandovi and the Zuari open) and the other was along the Mangalore coast

The understanding of relation between abiotic factors and plankton communities in the coastal waters is of large importance. The coastal zone serves as a mid-region for the land and the open sea, receiving high concentration of nutrients and potentially also increased content of any polluting substances, which can have a negative effect upon the development and growth of plankton organisms. The coastal regions and their inhabitants are also the first to receive the impact of any climatic change.

2.3 Work plan

2.3.1. Station location

Along the west coast 6 stations were fixed in two transects, three of them of the Goa coast and three off the Mangalore coast (Figs. 2.1 & 2.3) while along the east coast, 6 stations were fixed off the Kakinada region (Figs. 2.2 & 2.4). The details of sampling stations are shown in Table 2.1.

2.3.2 Study period and sampling frequency

The study was carried out during 2004 along the west coast and during 2005 along the east coast. sampling was done three times during the study period along each coast, representing the pre-monsoon, monsoon and post-monsoon seasons. Accordingly, samples were collected January, April & September along the west coast and in April September & November along the east coast.

Table 2.1. Details of sampling stations

West Coast

Location	**Station code**	**Position**		**Depth (m)**
		Latitude (N)	Longitude (E)	
Off Goa	1	$15^0 30'00''$	$73^0 35'00''$	30 m
	2	$15^0 30'00''$	$73^0 20'00''$	50 m
	3	$15^0 30'00''$	$73^0 00'00''$	100 m
Off Mangalore	4	$13^0 00'76''$	$74^0 38'11''$	30 m
	5	$13^0 00'00''$	$74^0 15'00''$	50 m
	6	$13^0 00'00''$	$74^0 03'30''$	100 m

East Coast

Location	**Station code**	**Position**		**Depth (m)**
		Latitude (N)	Longitude (E)	
Off Kakinada	1	$17^0 02'30''$	$82^0 25'00''$	30 m
	2	$17^0 00'00''$	$82^0 30'00''$	50 m
	3	$16^0 52'30''$	$82^0 33'00''$	100 m
	4	$16^0 43'00''$	$82^0 25'00''$	30 m
	5	$16^0 56'00''$	$82^0 27'00''$	50 m
	6	$16^0 45'00''$	$82^0 30'00''$	100 m

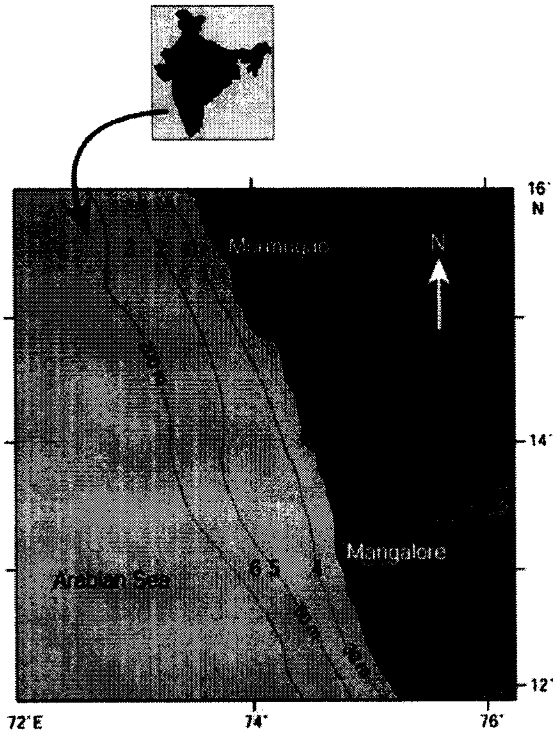


Fig. 2.1: Station locations along the west coast

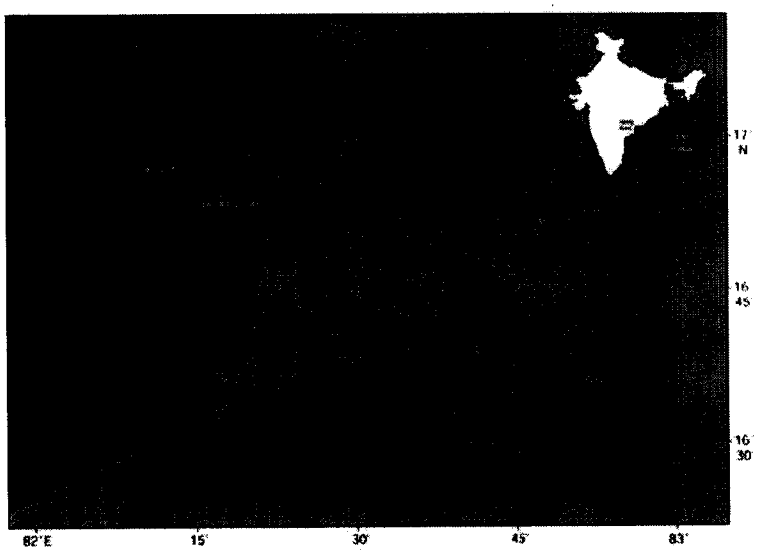


Fig. 2.2: Station locations along the east coast

Fig. 2.3: Satellite picture of the west coast of India (Goa and Mangalore)

Fig. 2.4: Satellite picture of the east coast of India (Kakinada)

CHAPTER 3:

Material & Method

3.1. Collection Methods

Water samples were collected at each station using the Niskin sampler (5L capacity). At 30 m stations, near-surface (1 m below surface) and near-bottom (1 m above bottom) samples were collected. At all other stations, near-surface, mid-depth (25 m below surface) and near-bottom samples were taken. Water samples were analysed for physical parameters, viz. temperature, salinity and dissolved oxygen; chemical parameters, viz. nitrate, phosphate and silicate and biological parameters, viz. chlorophyll *a* and mesozooplankton. Mesozooplankton samples were collected with a WP-2 closing net by making vertical hauls at all the stations, from near-bottom to surface or 30 m to surface, whichever was deeper.

3.1. 1 Measuring method for environmental parameters

Water samples from desired depths were collected using niskin sampler (5L capacity).

3.1.1a Temperature

Temperature of water samples collected at each depth was immediately measured using a centigrade thermometer, having a graduation of 0 - 50°C.

3.1.1b. Salinity

Salinity was measured by conductivity measurements using Autosal in the laboratory. A known quantity of seawater sample was passed through the conductivity cell to get the conductivity ratio. It was then converted to chlorinity from where the salinity value was calculated and expressed as practical salinity units (psu).

3.1.1c. Dissolved oxygen (DO)

Dissolved oxygen was estimated by Winkler method. (Grasshoff, et. al., 1983). Water samples were collected in DO bottles of 125 ml capacity. Care was taken to avoid air bubbles and the sample was fixed immediately by adding 1 ml manganous sulphate solution (Winkler A) and 1 ml alkaline iodide solution (Winkler B). The precipitate formed was dissolved in 1 ml concentrated sulphuric acid and the liberated iodine was titrated against standard sodium thiosulphate solution using starch an indicator.

3.1.2 Measuring method for chemical parameter

3.1.2a. Nitrate

Nitrate in the samples was first reduced quantitatively to nitrite by heterogeneous reduction by passing each buffered sample through an amalgamated cadmium column (Grasshoff, et. al., 1983). The measured absorbance was due to the initial nitrite in the sample and the nitrite obtained after the reduction of nitrate. This was measured at 543nm by a Shimadzu UV 1200 spectrophotometer.

3.1.2b. Phosphate

Dissolved reactive phosphate was measured by the method of (Grasshoff, et. al., 1983) in which the samples were made to react with acidified molybdate reagent and reduced using ascorbic acid. The absorbance of the resultant blue complex was measured at 880nm using Shimadzu UV 1200 spectrophotometer.

3.1.2c. Silicate

The determination of silicate in water was based on the formation of a yellow silicomolybdic acid when a nearly acidic sample was treated with a molybdate reagent. (Grasshoff, et. al., 1983). The yellow silicomolybdic acid was reduced to an intensely coloured blue complex using ascorbic acid as the reductant and the colour was measured spectrophotometrically at 810 nm by a Shimadzu UV 1200 spectrophotometer.

3. 1. 3 Measuring method for biological parameters

3.1.3a Chlorophyll *a* (Chl *a*)

Water samples from desired depths were collected using Niskin sampler (5L capacity). For phytoplankton biomass (Chlorophyll a) estimation, one litre of water sample was collected in duplicate and filtered through GF/F filter (dia. 47 mm; pore size - 0.7 μm). The filters were individually transferred into 20 ml Tarson vials and immediately frozen in liquid nitrogen until analysis. Chlorophyll a was extracted in dark for 12 hr by adding 10 ml of 90% acetone under refrigeration. Chlorophyll a content was estimated using a Turner design fluorometer.

3.1.3b Mesozooplankton

Zooplankton samples were collected by hauling a WP2 closing net (mouth area - 0.25 m^2 and mesh width - 200 μm), vertically from near-bottom to surface and the samples were preserved in 5% neutral formaldehyde. Biomass estimation, taxonomical and numerical analyses were carried out in the laboratory. Biomass was determined by displacement volume method and is expressed as ml.m-3. Taxonomical studies and numerical estimations were done from aliquots by splitting the samples (6.25%) using a Folsom Splitter.

Samples were examined under a stereoscopic binocular microscope for numerical counts and group identification. Some of the dominant groups were identified up to group level. Density of groups/families is expressed as No.m^{-3}.

3.1.3c Trophic relationship-calculation of carbon equivalent of phytoplankton and zooplankton biomass

Chlorophyll biomass obtained (mgC.m^{-3}) were integrated for the column (mgC.m^{-2}) and calculated with a conversion factor of 50 (Banse, 1988) for 50 m depth because below this depth nutrients and light penetration is generally less. In case of zooplankton, the displacement volume was converted to dry weight using a factor of 0.075 g dry wt ml^{-1} and then to carbon as 34% of the dry weight (Madhupratap, et. al., 1981 a). Energy required to sustain the zooplankton biomass was calculated based on gross growth efficiencies which was 0.3 in case of mesozooplankton (Ikeda & Motoda, 1978). The carbon equivalents for the study area and water column for each season and annual, were estimated separately for phytoplankton and zooplankton and are expressed as $KgC.m^{-2}$ for area and $KgC.m^{-3}$ for column.

3.1.3d Statistical analyses

Zooplankton abundance was converted into a lower triangular similarity matrix using Bray-Curtis coefficients (Bray and Curtis, 1957) and subjected to clustering and ordination techniques using the software PRIMER (version 5). Canonical Correspondence Analysis was performed to evaluate the relationships between environmental variables and zooplankton groups. (ter Braak, 1995) using the Multi-Variate Statistical Package program version 3.1 (Kovach, 1998).

CHAPTER 4:

Environmental Parameters

4.1 West coast (off Goa and off Mangalore)

4.1.1. Environmental Parameters

4.1.1.1. Physical Parameters

4.1.1.1a. Temperature

Temperature ranged from 19.02 to 29.6 ^{0}C at the off Goa transect and 20.6 to 30.9^{0}C at the off Mangalore transect during the study period. Temperature at the off Goa transect ranged from 24.6 to 29.6 ^{0}C during pre-monsoon, 19.02 to 29.4 ^{0}C during monsoon and 27.8 to 28.9^{0}C during post-monsoon. At the off Mangalore transect the range in temperature was from 26.1 to 30.9^{0}C, 20.7 to 29.3^{0}C and 27.7 to 28.5^{0}C during the above mentioned seasons, respectively (Figs. 4.1a-c & 4.2 a-c).

Vertical distribution of temperature was relatively stable at both the transects during the pre-monsoon and post-monsoon seasons, but during the monsoon season, a sharp decrease was observed with depth at some stations. The lowest temperatures at both the transects were recorded during this season. Along the Goa transect the lowest of 19.02^{0}C was recorded at Stn. 3 (90 m) (Fig. 4.1 b) and along the Mangalore transect it was 20.6^{0}C at Stn. 6 (90 m) (Fig. 4.2 b)

4.1.1.1b. Salinity

Salinity ranged from 33.4 to 36.6 psu at the off Goa transect and 32.9 to 36.1 psu at the off Mangalore transect during the study period (Figs. 4.3 a-c & 4.4 a-c). During the pre-monsoon season along the Goa transect , it ranged from 35.5 to 36.1 psu. During the monsoon season, it ranged from 34.7 to 36.5 psu and 33.4 to 35.9 psu during the post-monsoon season. At the off Mangalore transect, it ranged from 35.1 to 36.1 psu during pre-monsoon, 34.7 to 35.2 psu during monsoon and 32.9 to 34.8 psu during post-monsoon.

Salinity was more or less stable at both the transects during the pre-monsoon season while it was low at the off Goa transect during the monsoon and the post-monsoon seasons (Fig. 4.3 b, c). Overall, salinity was high during the pre-monsoon season and an increase with depth was noticed during all the three seasons. Along the Mangalore transect, pre-monsoon and monsoon recorded (Fig. 4.4 a, b) were closely similar to that of Goa transect, but during the post-monsoon season the values recorded were relatively low compared to that of the Goa transect (Fig. 4.4 c). Increase in salinity with depth though marginal was observed at most of the stations during all the stations.

4.1.1.1c Dissolved Oxygen (DO)

DO ranged from 0.23 to 5.64 ml l^{-1} at the off Goa transect and 0.17 to 4.79 ml l^{-1} at the off Mangalore transect (Figs. 4.5 & 4.6). Seasonal variations were observed in DO concentration at both the transects. It ranged from 1.6 to 4.33 ml l^{-1} during the pre-monsoon season, 0.23 to 5.30 ml l^{-1} during the monsoon season and 3.25 to 5.64 ml l^{-1} during the post-monsoon season along the off Goa transect. Along the off Mangalore transect, it ranged from 1.65 to 4.27 ml l^{-1} during pre-monsoon season, 0.17 to 4.28 ml l^{-1} during monsoon season, and 3.02 to 4.56 ml l^{-1} during post-monsoon season. The range in seasonal variation observed was very similar for both transects.

Generally well oxygenated condition was prevailing during the pre-monsoon season at both transects. However, low values were observed at a few near-bottom stations, viz. 90 m at Stn. 3 (1.6 ml l^{-1}) and 30 m at Stn. 4 (1.65 ml l^{-1}). The near-surface value at Stn. 6 was low (2.35 ml l^{-1}) compared to all other near-surface values. DO values at the off Goa transect during this season were slightly higher than that of off Mangalore transect. During the monsoon season, the DO was slightly higher at off Goa transect than that of the off Mangalore transect. The noticeable feature was that most of the sub-surface and near-bottom values were at the sub-oxic levels during this season along both the transects. (Figs. 4.5 & 4.6). Stations along both the transects were well oxygenated during the post-monsoon season, but at the off Goa transects DO was slightly higher than the off Mangalore transect. However, the near-bottom values were low at all the stations and higher values were recorded mostly at the near surface.

4.1.1.2. Chemical Parameters

4.1.1.2a. Nitrate

Nitrate content during the study period ranged from 0.01 to 8.05 μM at the off Goa transect and 0.003 to 5.16 μM at the off Mangalore transect (Figs. 4.7 & 4.8). It ranged from 0.01 to 2.83 μM during pre-monsoon, 0.07 to 4.97 μM during monsoon and 0.04 to 2.36 μM during post-monsoon at the off Goa transect. At the off Mangalore transect, the range was from 0.01 to 2.76 μM during pre-monsoon, 0.07 to 5.16 μM during monsoon and 0.01 to 3.69 μM during post-monsoon. During the pre-monsoon season, the highest values were recorded at 90 m of Stn. 3 and 30 m of Stn. 4 where the surface DO was low. Generally, NO_3 maxima was seen in sub-surface or near-bottom layers. Very low values were recorded at near-surface and mid-depths. Nitrate values were relatively higher at the off Mangalore transect compared to the off Goa transect for the respective seasons.

4.1.1.2b. Phosphate

Phosphate content ranged from 0.01 to 3.41 μM at the off Goa transect and 0.01 to 3.83 μM at the off Mangalore transect (Figs .4.9 & 4.10). Along the Goa transect, it ranged from 0.01 to 3.41 μM during the pre-monsoon, 0.02 t o 1.18 μM during the monsoon and 0.03 to 0.33

μM during the post-monsoon seasons.(Fig. 4.9 a-c). Off Mangalore transect the range was from 0.01 to 3.83, 0.01 to 0.57 and 0.02 to 0.31 μM for the respective periods. (Fig. 4.10 a-c). The ranges observed at both the transects were closely similar for the respective season, except that the highest recorded value during the monsoon season at the Goa transect was almost 3 times higher than that of Mangalore transect.

During pre-monsoon season, phosphate was generally high in the near-surface or sub-surface depths. Phosphate content on the whole was higher at off Goa transect compared to off Mangalore transect.

4.1.1.2c. Silicate

Silicate ranged from 0.01 to 20.27 μM at the off Goa transect and 0.17 to 8.27 μM at the off Mangalore transect during the study period (Figs. 4.11 & 4.12). The range was from 0.37 to 3.12 μM during pre-monsoon, 0.01 t o 20.27 μM during monsoon and 1.39 to 3.85 μM during post-monsoon at the off Goa transect. Along the Mangalore transect the range was from 0.47 to 5.55 μM during pre-monsoon, 0.17 to 8.27 μM during monsoon, and 1.74 to 6.37 μM during post-monsoon. The silicate content was higher at off Mangalore transect during all the seasons compared to off Goa transect except for the highest value observed during the monsoon season. Silicate content was generally high in near-bottom waters at all the stations.

4.2. East coast (off Kakinada)

4.2.1.Environmental Parameters

4.2.1.1. Physical Parameters

4.2.1.1a. Temperature

Temperature ranged from 24 to 32^{0}C off the Kakinada coast during the study period. A reduction with depth was observed during all the seasons. It ranged from 24 to 31^{0}C during the pre-monsoon, 26.8 to 30.4^{0}C during the monsoon and from 24.5 to 32^{0}C during the post-monsoon seasons. (Fig. 4.13).

Temperature decrease with depth was sharp during the pre-monsoon. The variation was as much as 7^{0}C at 100 m (Stns. 3 & 6). During the monsoon temperature drop was gradual with a 1^{0}C except at Stn. 3 where there was a 2^{0}C drop. During the post-monsoon, temperature remained almost stable in the water column the only variation noted was at Stn. 6 where the difference between near-surface and near-bottom was 7.5^{0}C. Generally the temperature recorded along the east coast was higher than that of the west coast, particularly during the monsoon season.

4.2.1.1b. Salinity

Salinity ranged from 22.13 to 36.1 psu during the study period. Seasonal ranges were, 22.1 - 34.8, 31.8 - 36.1 and 24.0 - 35.8 psu during the pre-monsoon, monsoon and the post-monsoon seasons, respectively (Fig. 4.14). Salinity recorded was considerably low during all the seasons, compared to that of west coast.

The near-surface salinity was always lower compared to the near-bottom salinity with only few exception, but those values were also marginally different. (Fig. 4.14). However, during the monsoon and post-monsoon seasons the near-surface values at most of the stations were 3 to 6 psu lower compared to the near-bottom values.

4.2.1.1c. Dissolved Oxygen (DO)

DO was generally high during the pre-monsoon followed by monsoon and post-monsoon seasons. It ranged from 1.23 to 7.81 ml l^{-1} during the pre-monsoon, 2.58 to 6.45 ml l^{-1} during the monsoon and 0.9 to 6.32 ml l^{-1} during the post monsoon seasons. (Fig. 4.15). Overall, there was a decrease in DO content with increasing depth. High surface values were recorded during the pre-monsoon season. Low values were recorded at Stns. 3 & 6 during pre-monsoon, and at Stn. 3 during monsoon and at Stn. 6 during post-monsoon incidentally at 100 m depth at all the stations . Compared to the west coast DO content was relatively high along the east coast stations.

4.2.1.2 Chemical Parameters

4.2.1.2a. Nitrate

Nitrate values ranged from 0.01 to 19.27 µM during the study period, with values ranging from 0.01 to 19.27 µM (premonsoon), 0.08 to 15.87 µM (monsoon) and 0.05 to 3.61 µM (post-monsoon) (Fig. 4.16).

Generally low nitrate content was recorded at the near-surface which increased with depth during all the seasons. However very high values for all the seasons were recorded at 100 m depth (Stn. 3 & 6), the highest being recorded during the pre-monsoon season (17.69 & 19.27 µM at Stns. 3 & 6, respectively). At Stn. 5 (50 m) also a closely similar value was recorded (17.76 µM). Generally, the NO_3 content recorded during the post-monsoon season was lower compared to other seasons.

4.2.2 b. Phosphate

It ranged from 0.07 µM to 5.23 µM in the entire study area. The seasonal ranges were (0.07 - 3.63 µM (pre-monsoon season), 0.18 - 5.23 µM (monsoon season) and 0.19 - 5.23 µM (post-monsoon season) (Fig. 4.17) . No particular trend was observed in the seasonal distribution. The vertical profile however, showed that at most of the stations, PO_4 content was relatively higher in the near-bottom layers. An increasing trend with depth was observed during the pre-monsoon season, at Stns. 1, 3 and 5. During the monsoon, an increase with depth was evident at Stns. 2, 3, 4 and 5, and during the post-monsoon at Stns. 2, 5 and 6 (Fig. 4.17 a-c). Although a reduction was noticed at mid-depths, the near-bottom values were higher than near-surface values.

4.2.1.2c. Silicate

Silicate values ranged from 0.16 µM to 26.6 µM during the study period along the Kakinada coast (Fig. 4.18). The seasonal range was from 0.16 - 14.57 µM (pre-monsoon), 3.02 - 25.13 µM (monsoon) and 5.57 - 26.6 µM (post-monsoon). The overall trend observed was a decrease with depth, but an increase at the near-bottom layers, particularly during the pre-monsoon (Stns. 2, 5 & 6) and post-monsoon seasons (Stns. 2, 3, 5 & 6) were clearly visible. At Stns. 1 & 4, a decrease was registered during both the seasons, while Stn. 3 pre and post-monsoon recorded an increase during the former period. During the monsoon season there was an increase in silicate content with increasing depth at all the stations except at Stn. 6 where a decrease was observed at 100 m depth.

4.3. Discussion

The coastal areas of the west and east coast had different physical and chemical conditions prevailing during the period of study. Nutrients were available for the organism to carry out their biological activities in more or less same proportion at both the coasts with the land runoff influencing the west coast and the river runoff influencing the east coast. As observed by Prasanna Kumar, et. al., (2001), nutrients-rich upwelled waters from the coasts of Somalia and Arabia were being transported to the central Arabian Sea which enhances the biological productivity of the west coast. Although the nutrients were present in adequate concentration along the east coast also due to the stratification experienced in the surface layers the same was not be available for primary production as in the case of the Arabian Sea. The winds along the east coast are not as strong as along the west coast to break the stratification to allow mixing of nutrient rich waters. In the Bay of Bengal, upwelling has been reported to be confined very close to the coast (within 40 km) along the southwestern boundary during summer and also appears to be episodic (Murty and Varadachari, 1968; Shetye, et. al., 1991). An examination of the basin-wide wind revealed that in the Arabian Sea the wind speed is about 3–4 m/s during June, July and August which is stronger than that of the Bay of Bengal and is consistent with COADS climatology (Woodruff, et. al., 1987).

The overall water temperature was higher in the Bay of Bengal during all the three seasons which was as high as 32°C. The CCA analysis also corroborates the high temperature prevailing along the Kakinada coast. Along the west coast, the off Mangalore transect recorded the highest temperature (30.9 °C) as compared to the off Goa transect (29.6 °C). Along the west coast, the annual range of water temperature was from 19.0 to 30.9^{0}C, and along the east coast it was from 24 to 32^{0}C. The annual variation of temperature along the in Goa coast was from 19.02 to 29.60^{0}C as against off Mangalore 20.6 to 30.9^{0}C. Although the overall water temperature did not show much seasonal variations along both the coasts, a general decrease was seen during the monsoon season. This could be attributed to the coastal upwelling prevailing during this season which brings the cold bottom waters to the surface. Mitbavkar & Anil, (2000), recorded temperatures ranging from 26 to 32^{0}C in the Goa waters. Achuthankutty, et. al., (1998) have reported a drop in both surface and bottom temperatures in the coastal waters of Goa during the monsoon season (27.2 to 24^{0}C and 27.2 to 20^{0}C, respectively). The same was noticed in this study also although the absolute values were slightly different. The SST during the monsoon and post-monsoon in the Arabian Sea were lower due to upwelling and winter cooling, respectively (Gauns, et. al., 2005) while in the Bay of Bengal the SSTs are higher which in association with low salinity leads to stratification (Sen Gupta & Naqvi, 1984; Rao, et. al., 1994, Madhupratap, et. al., 2003). Bimodal seasonal oscillation of SST was recorded in the coastal waters of Mangalore (Kumar and Sampath, 1984) while for the same area unimodal and trimodal seasonal fluctuations of SST was recorded by Rajanna, (1997) and Mridula, (1999). Bimodal oscillation with two maxima, another during post-monsoon and one during pre-monsoon was recorded by Raghavendra, (2004). During the present study, high temperature was recorded during the pre-monsoon season along the Goa transect while at the off Mangalore it was recorded during the post monsoon season.

Salinity variation along the west coast for the study period was 32.9 - 36.6 psu while along the east coast it was 22.1 - 36.1 psu. Mitbavkar & Anil, (2000), recorded 30 to 37 psu salinity in the Goan waters. However, Achuthankutty, et. al., (1998) have recorded surface salinity ranging from 15 – 26.4 psu and bottom salinity ranging from 26.4 – 35.9 psu for Goa waters during the monsoon season. Salinity was high at the west coast of India both the transect and low at the off Kakinada in the east coast which was as low as 22.1 psu. The trend remained more or less similar along both the coast. Seasonally also it did not show much difference during the study period except that the near-surface along the east coast was relatively low which may be the influence of the north east monsoon prevailing and bringing in freshwater influx.

Dissolved Oxygen along the west coast ranged from 0.17 to 5.64 ml l^{-1} as against the east coast range of 0.9 to 7.81 ml l^{-1}. Along the Goa coast it ranged from 0.23 to 5.64 ml l-1 whereas along the Mangalore coast it varied from 0.17 to 4.79 ml l^{-1} . The highest DO value for the study period was recorded along the east coast which was about 7.81 ml l^{-1} and was recorded during the pre-monsoon at the near-surface waters of Stn. 3. Along the west coast the off Goa (5.64 ml l^{-1}) transect had relatively higher values of DO compared to off Mangalore transect (4.79 ml l^{-1}). Reddy, et. al., (2005) observed low DO during pre-monsoon season along the Mangalore coast which was indicated to be due to after effects of tsunami which hit the east coast during December 2004. Naqvi & Ansari, (2006), attributed the overall depletion of DO to the increased anthropogenic perturbations and intensifying seasonal upwelling. Ramesh, (1989), Mridula, (1999), D'Souza, (2001) and Katti, et. al., (2003) observed a decreasing trend of DO during the post-monsoon which could be due to its utilization by organic matter and by heterotrophic planktons. For the coastal waters of Goa, very low DO values (0.06 – 0.96 ml l^{-1}) were reported during the monsoon season and was attributed to upwelling effect (Achuthankutty, et. al., 1998). The upper water column showed uniform distribution of DO as it is the mixed layer depth. At the sub-surface depth there was a sudden decrease, particularly during monsoon season along west coast. During the south west monsoon, the land run off brings in lots of nitrogenous and organic matter. DO is utilised to break down these compounds and in the process it gets depleted. However, the overall DO was high along the east coast as compared to the west coast.

Nutrients supply at the surface layers is mostly from regenerated sources, brought up by the upwelling which is a regular phenomenon taking place during the monsoon season and also by the input of external sources such as land and river runoff. (Qasim, 1977) The summer monsoon winds in the Arabian Sea could introduce nutrients to the euphotic zone, by a variety of processes such as wind-driven mixing, upward Ekman pumping and lateral advection of upwelled waters from the coastal regions. (Prasanna kumar, et. al., 2001) However, similar winds were insufficient to break the strong stratification through wind-driven mixing in the Bay of Bengal and coupled to this is the non-existence of strong coastal upwelling which further eliminates the possibility of nutrient input to the upper ocean.

Phosphate concentration ranged from 0.01 µM during pre-monsoon and monsoon and the highest range 3.83 µM during pre-monsoon along the west coast. Seasonal annual range of phosphate ranged from 0.01 to 5.6 µM was reported in the Vishakapatnam harbour (Satyanarayana, et. al., (1994). In the present study, it ranged from 0.07 µM pre-monsoon to 5.23 µM post-monsoon in the Kakinada waters. In the coastal waters of Goa Verlecar, (1987) reported the phosphate range to be 0.003 to 0.08 µM. Other reports are, Verlecar, et. al., (2006) - 1.73 µM, and Mitbavkar & Anil, (2000) - 0.01 to 0.2 µM, Goswami and Padmavathi, (1996) - 0.06 to 0.07 µM. In the present study, PO_4 values were the lowest (0.01 µM) and highest (3.41 µM) during pre-monsoon along the Goa coast while off the Mangalore coast, the lowest value was 0.01 µM was recorded during pre-monsoon and monsoon seasons, while the highest of 3.83 µM was recorded during pre-monsoon season. Subrahmanyan, (1959) observed the values ranging from 0.004 and 0.05 µM along the west coast, Noble, (1968) observed it to vary from 0.007 to 0.07 µM in the North Kanara coast, Reddy and Sankaranarayan, (1968) recorded the values ranging from 0.02 to 0.05 µM at off Mangalore coast. They also have reported the nutrient enrichment in the coastal waters along the west coast of India during monsoon. Suresh and Reddy, (1978) opined that the high values could be brought either by the added nutrients during monsoon, by advection of water by horizontal currents and vertical circulation. Suresh, et. al., (1978) observed that vertical circulation prevailing during pre-monsoon season increases the phosphate concentration. Lingadhal, (1991) observed phosphate values ranging from traces to 0.21 µM in the coastal waters of Thannirbhavi (Mangalore) while Katti, et. al., (2002) obseved values in the range of 0.002 to 0.1 µM. Phosphate concentration was found to be low in the euphotic zone in the present study during all the seasons as phytoplankton utilizes it for photosynthesis. During the monsoon and post-monsoon seasons along the west and east coast its content was relatively higher which can be attributed to the land and river runoff, respectively which brings in nutrients.

Nitrate range recorded presently for the west coast was 0.003 µM to 8.05 µM and for the east coast was 0.01 µM to 19.27 µM. Mitbavkar & Anil, (2000), recorded 0.04 to 1.1 µM in the Goan waters. NO_3 was high in the east coast as compared in the west coast which was as high as 19.27 µM. values of 1.69 µM (Reddy, 1977) , 1.2 µM (Eknath, 1978), 0.007 to 2.01 µM, (Katti, et. al., 2001) and 0.12 to 0.9 µM, (Katti, et. al., 2002) have been reported from the Karnataka coast. Nitrate values off Mangalore were reported to be ranging from 0.02 to 2.4 µM (Lingadhal, 1991). (Bhattathiri, et. al., 1996) have reported 2.8 µM nitrate at 10m depth at the off Mangalore due to strong upwelling. De Souza, et. al., (1996) accounted for 2 µM nitrate in the surface layers of northern latitudes due to winter cooling and convective mixing. High concentration of nitrate (4 µM) was observed by Prasannakumar, et. al., (2001) in the surface layers of the northern Arabian Sea during winter. Later in 2004 they reported the presence of thin lens of nitrate (0.5 µM) in the upper 10 m which occurs in locations with low salinity in the southwest coast which was said to have originated from the Bay of Bengal.

Sardessai and Sundar, (2007) reported high nitrate concentration (4 μM) due to the monsoon runoff along the Goa coast.

Silicate values ranged along the west coast from 0.01 μM (monsoon) to 20.27 μM (monsoon). Along the east coast it ranged from 0.16 μM (pre-monsoon) to 26.6 μM (post-monsoon). Mitbavkar & Anil, (2000) recorded 0.02 to 2 μM in the Goan waters. Coastal waters of Kanara showed a maximum of 5.3 μM, Lingadhal, et. al., 1998, recorded a range which fluctuated from traces to 2.4 μM, while Katti, et. al., (2001) recorded a range from 0.07 to 1.7 μM in coastal waters of Karnataka. Jayaraman, (1951), Varma & Reddy, (1959) and Subrahmanyan & Sengupta, (1965) observed the south-west monsoon period corresponding with high silicate content and lowering of salinity as a result of large influx of river waters, rich in silicate. Concentration of silicate either depends on the input from rivers or from diatoms. Lingadhal, (1991, 1995), Liss, (1978) have observed a close correlation between silicate and salinity. Ramamurthy, (1963) recorded an inverse relationship with salinity along the west coast of India.

Overall the nutrients were high in the east coast due to the river runoff which brings in nutrients and slightly elevated values were observed at the 30 m depths during the monsoon season along the west coast of India. The nutrient availability has direct implications on the biological productivity, particularly the phytoplankton. (see Chapter-5). The biological production did not show any increase even though the nutrients were high along the east coast. Sub-surface chlorophyll maxima were observed during the monsoon which can be supported with the high nutrients availability during this season along the west coast. Along the east coast, the chlorophyll production was high at the surface which was due to the high nutrients found at the surface.

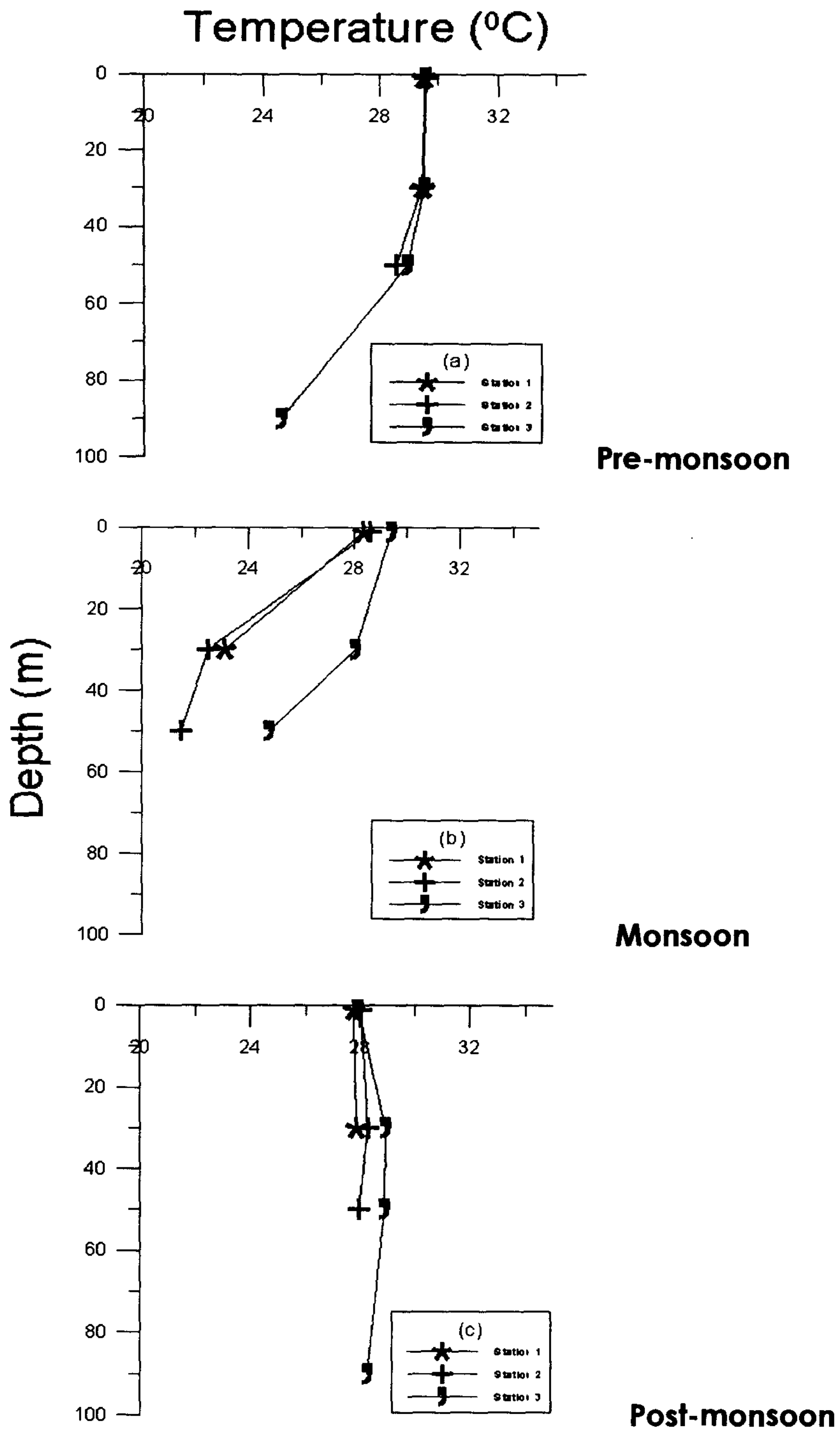


Fig. 4.1. Vertical distribution of Temperature along off Goa transect during different seasons

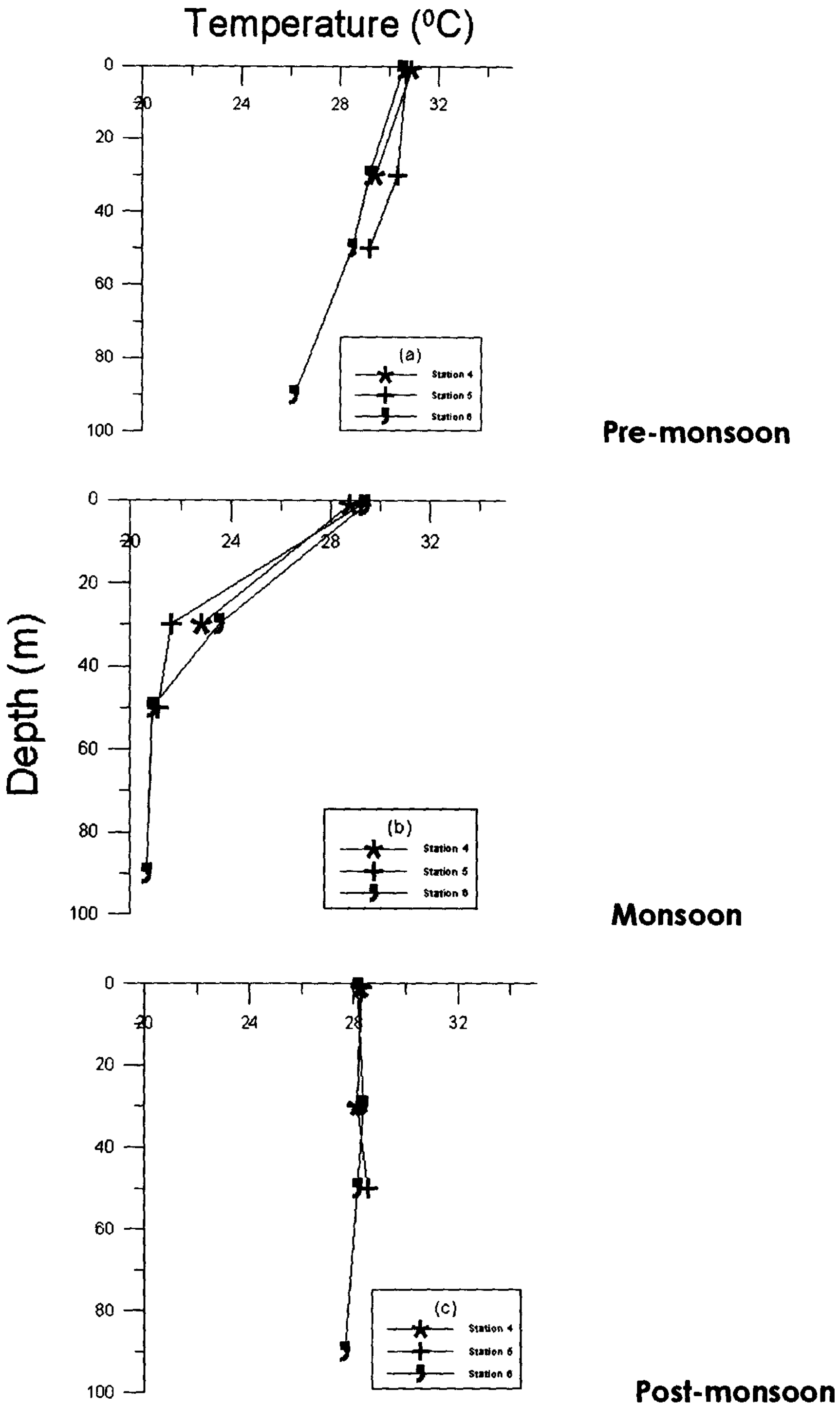


Fig. 4.2. Vertical distribution of Temperature along off Mangalore transect during different seasons

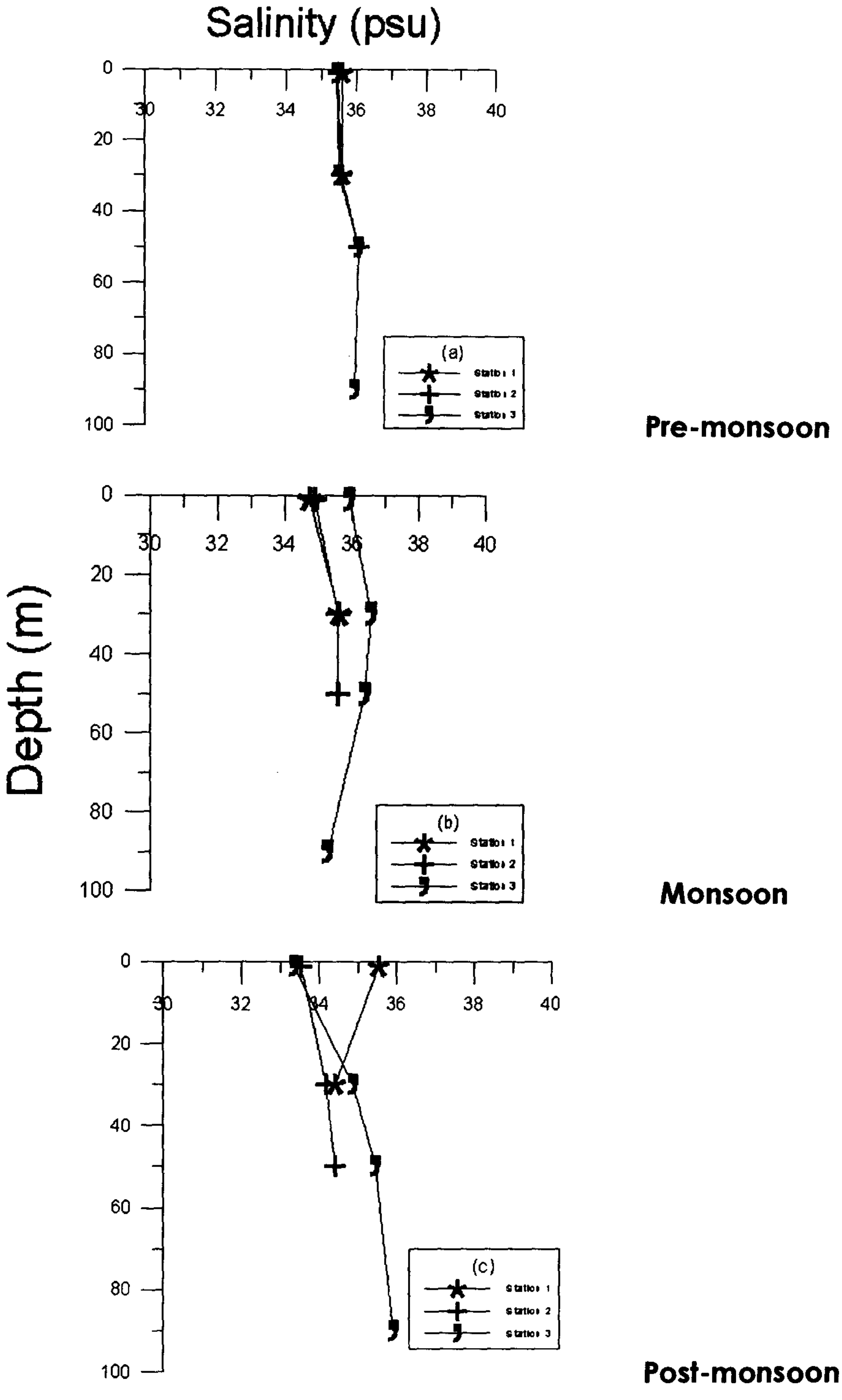


Fig. 4.3. Vertical distribution of Salinity along off Goa transect during different seasons

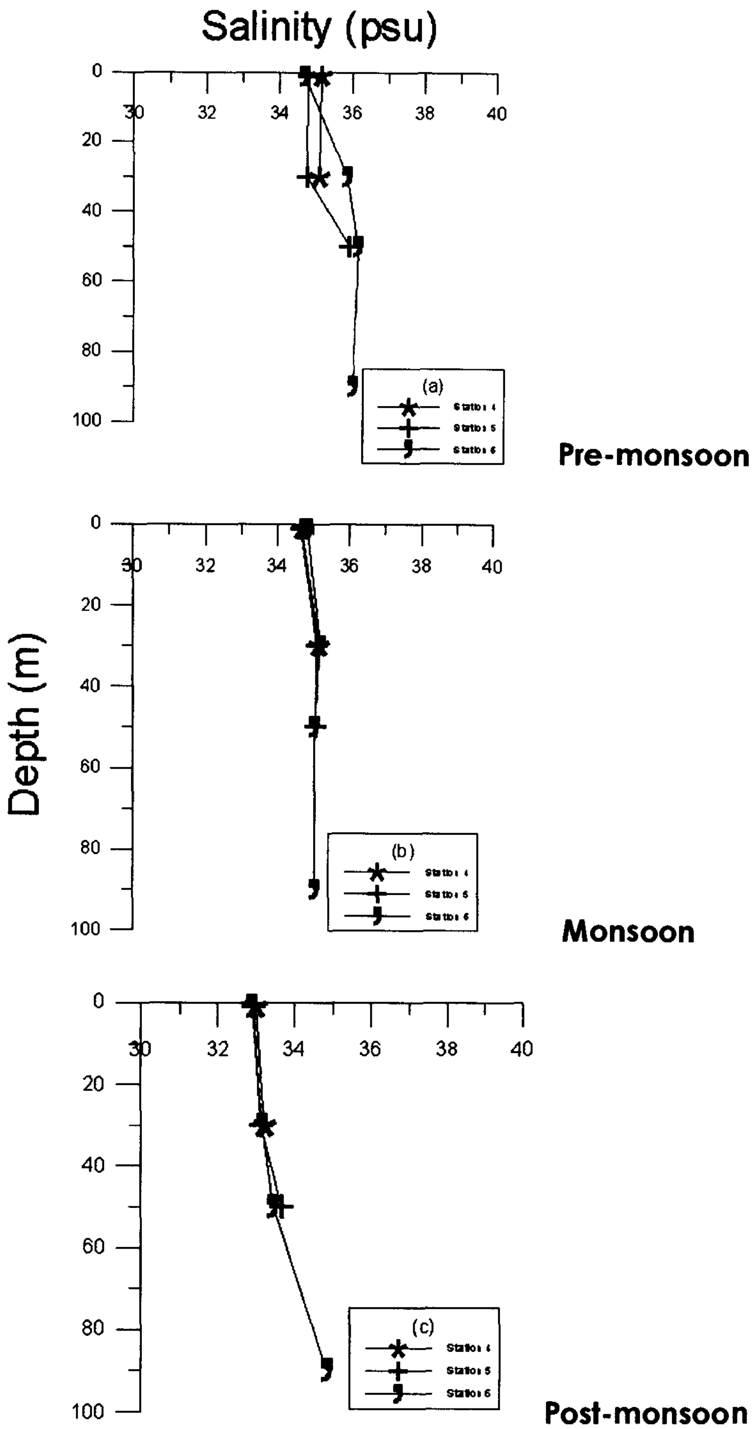


Fig. 4.4. Vertical distribution of Salinity along off Mangalore transect during different seasons

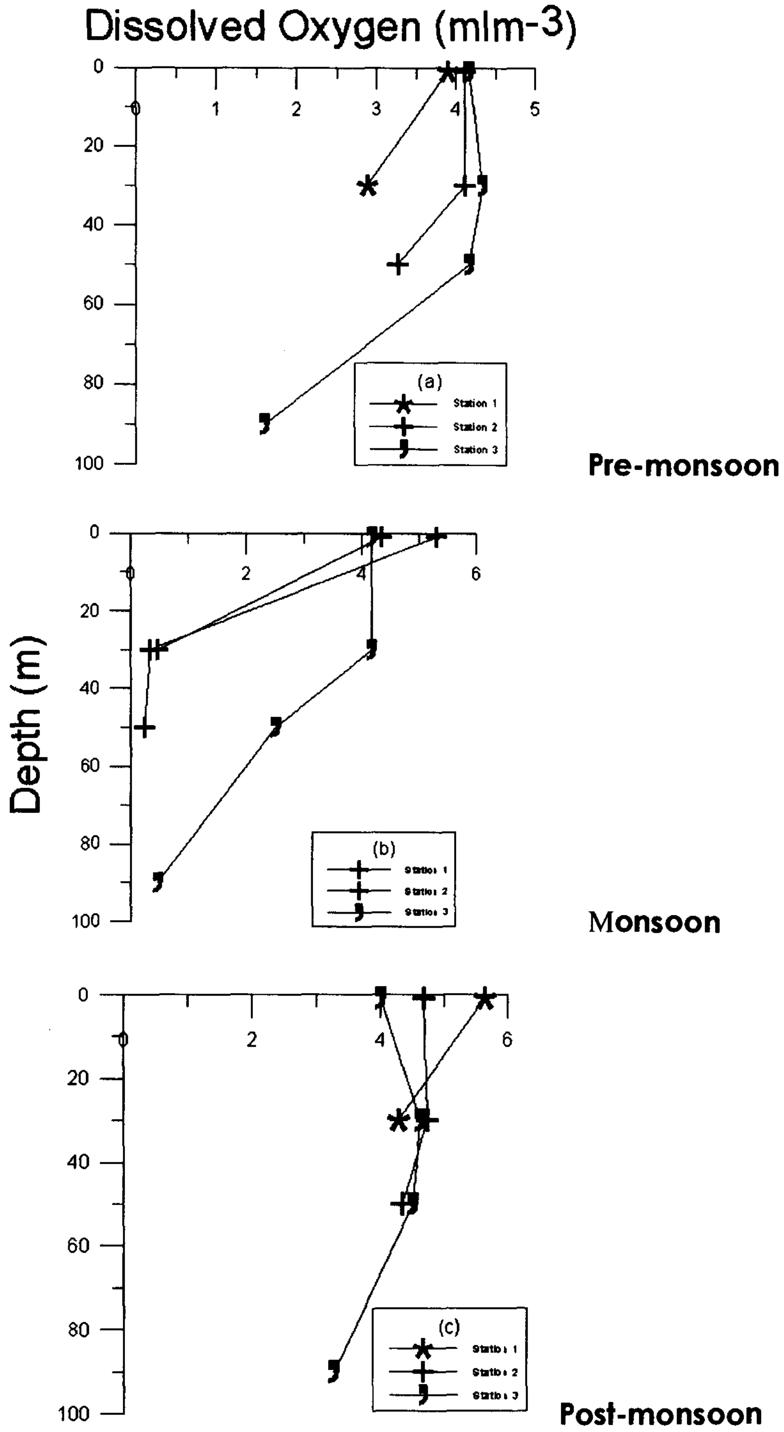


Fig. 4.5. Vertical distribution of Dissolved Oxygen along off Goa transect during different seasons

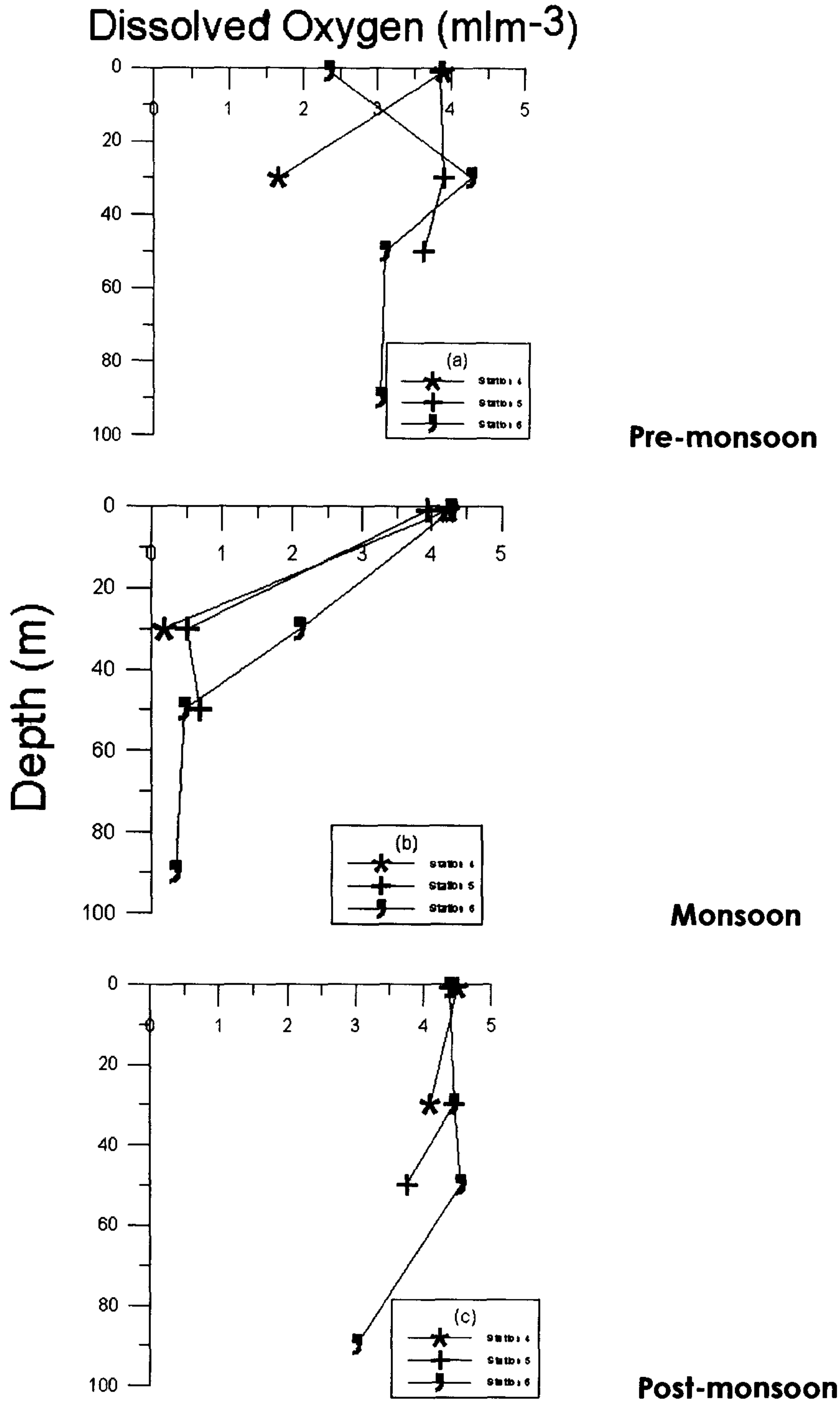


Fig. 4.6. Vertical distribution of Dissolved Oxygen along off Mangalore transect during different seasons

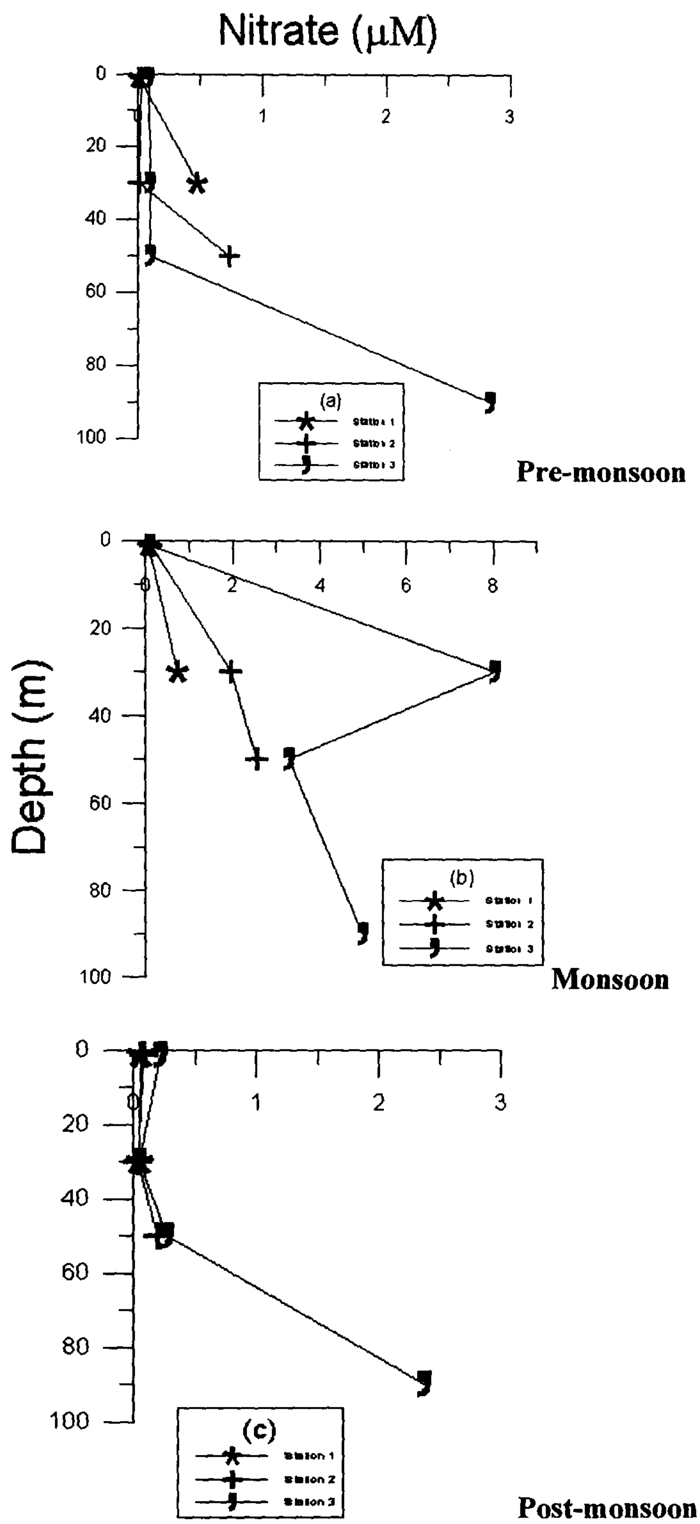


Fig. 4.7. Vertical distribution of Nitrate along off Goa transect during different seasons

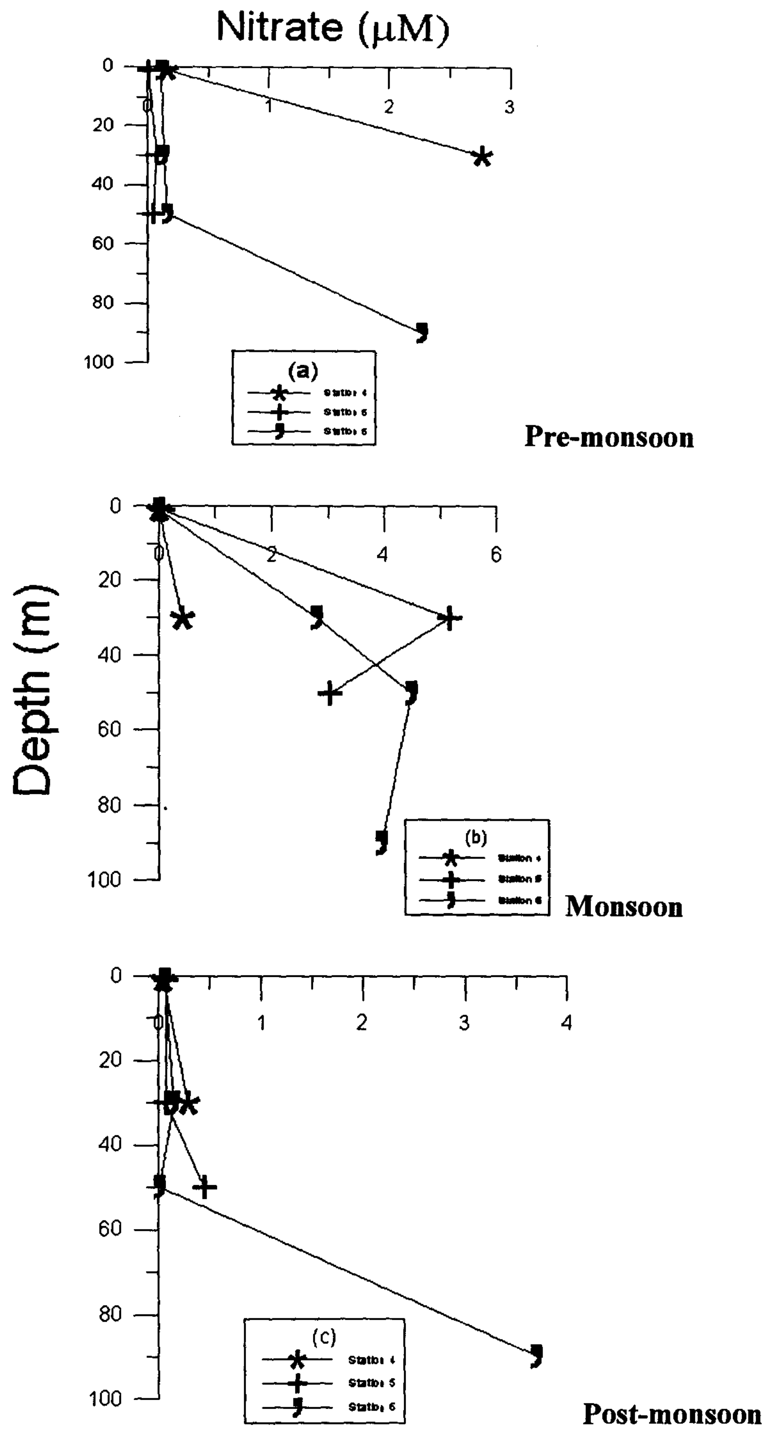


Fig. 4.8. Vertical distribution of Nitrate along off Mangalore transect during different seasons

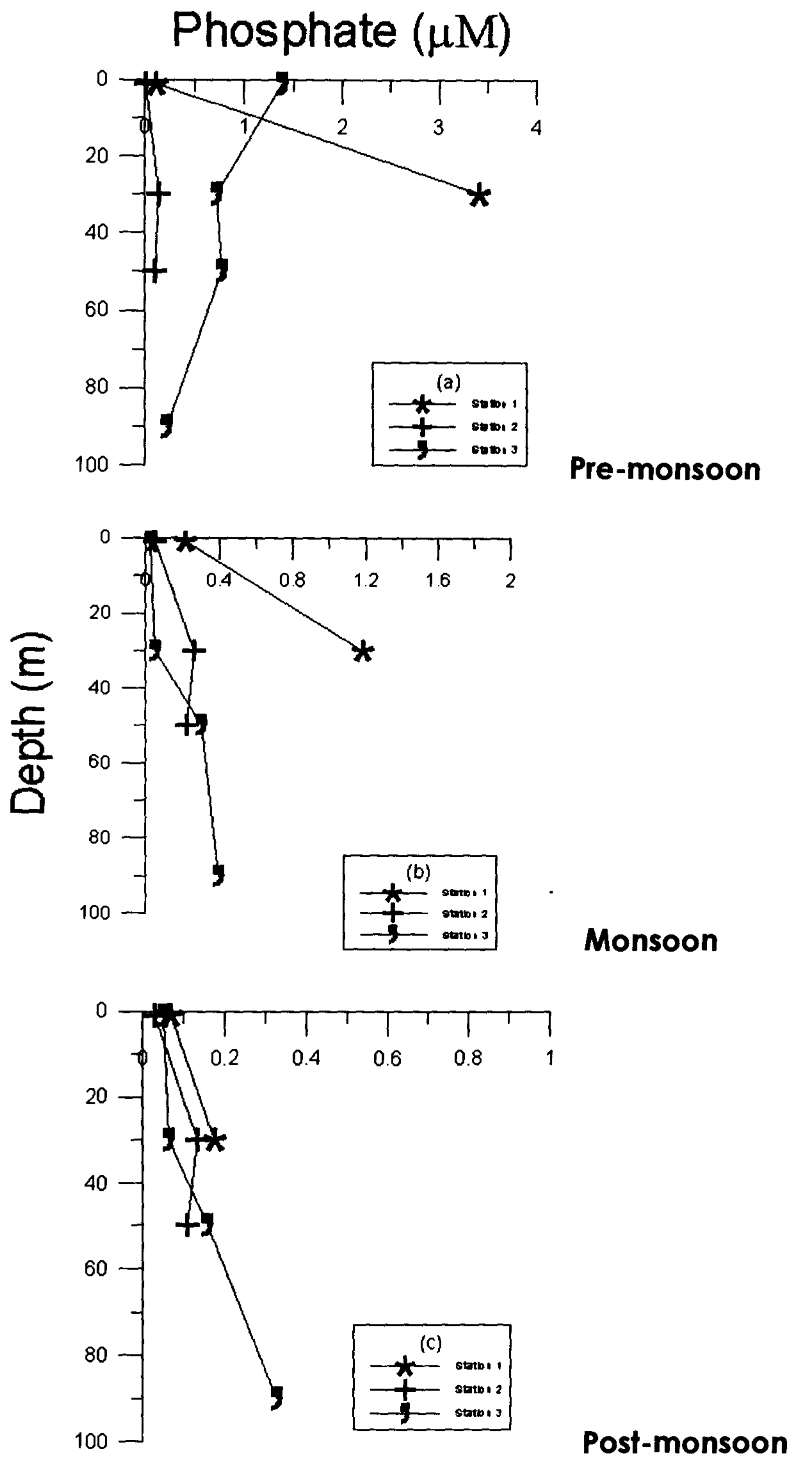


Fig. 4.9. Vertical distribution of Phosphate along off Goa transect during different seasons

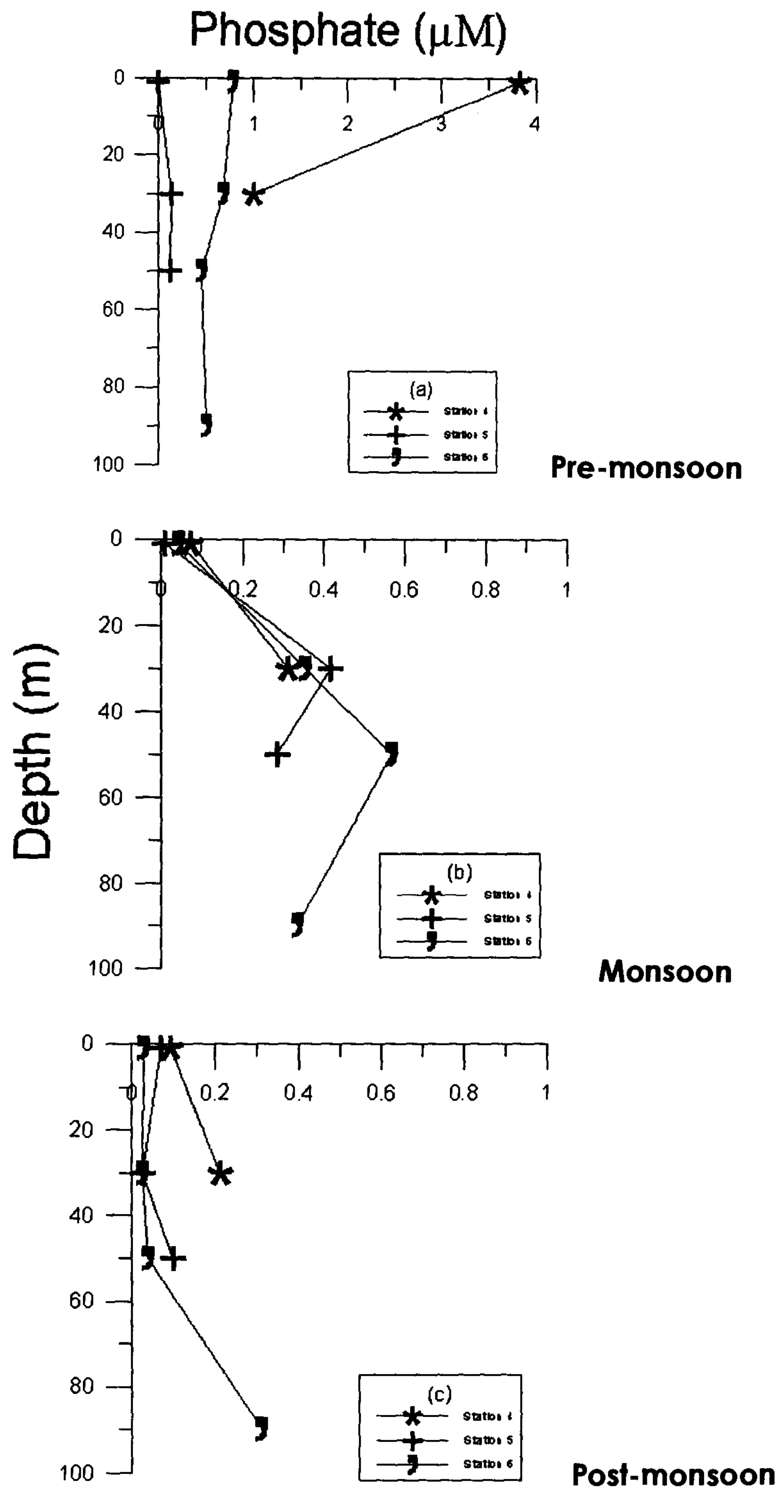


Fig. 4.10. Vertical distribution of Phosphate along off Mangalore transect during different seasons

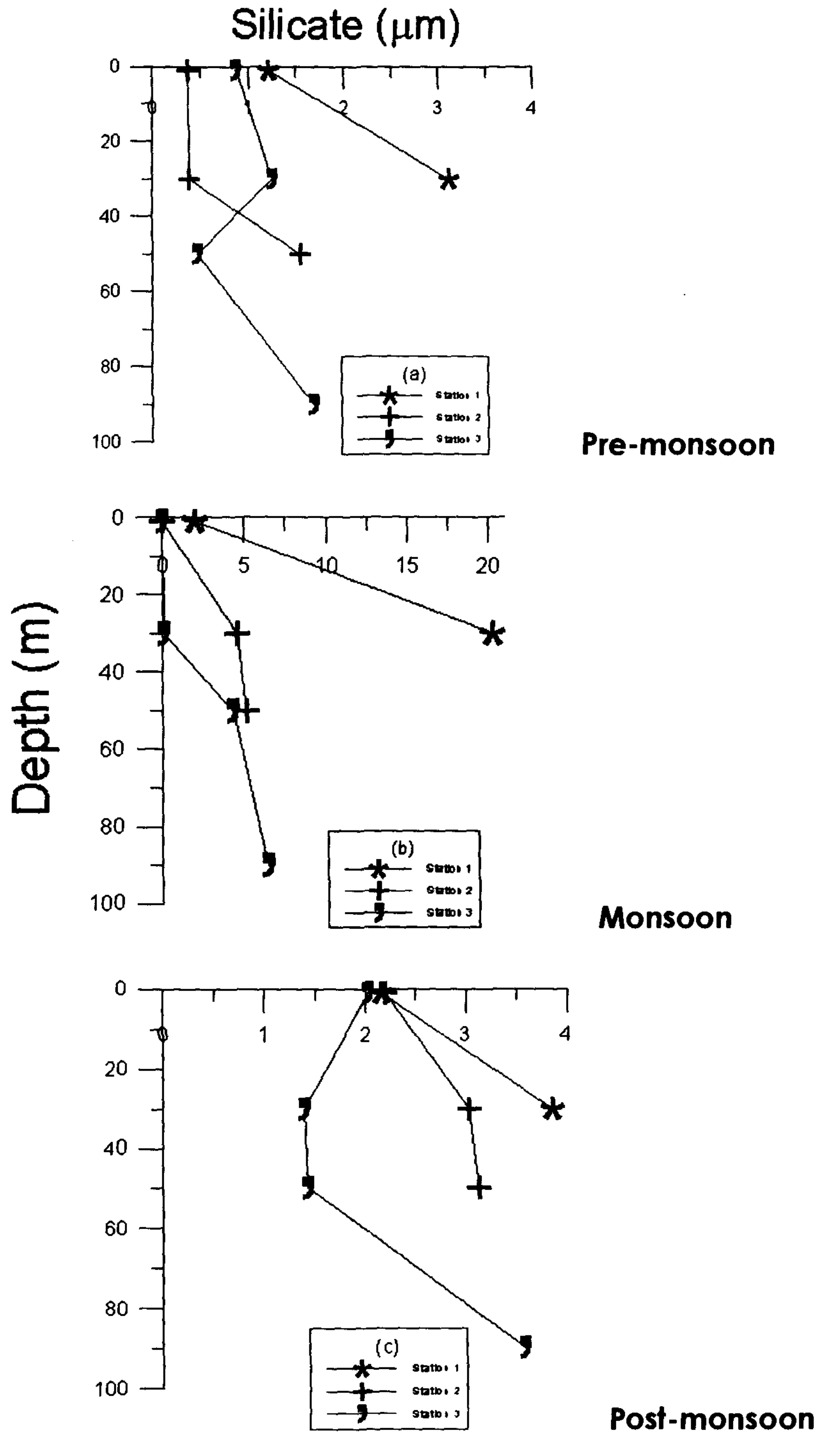


Fig. 4.11. Vertical distribution of Silicate along off Goa transect during different seasons

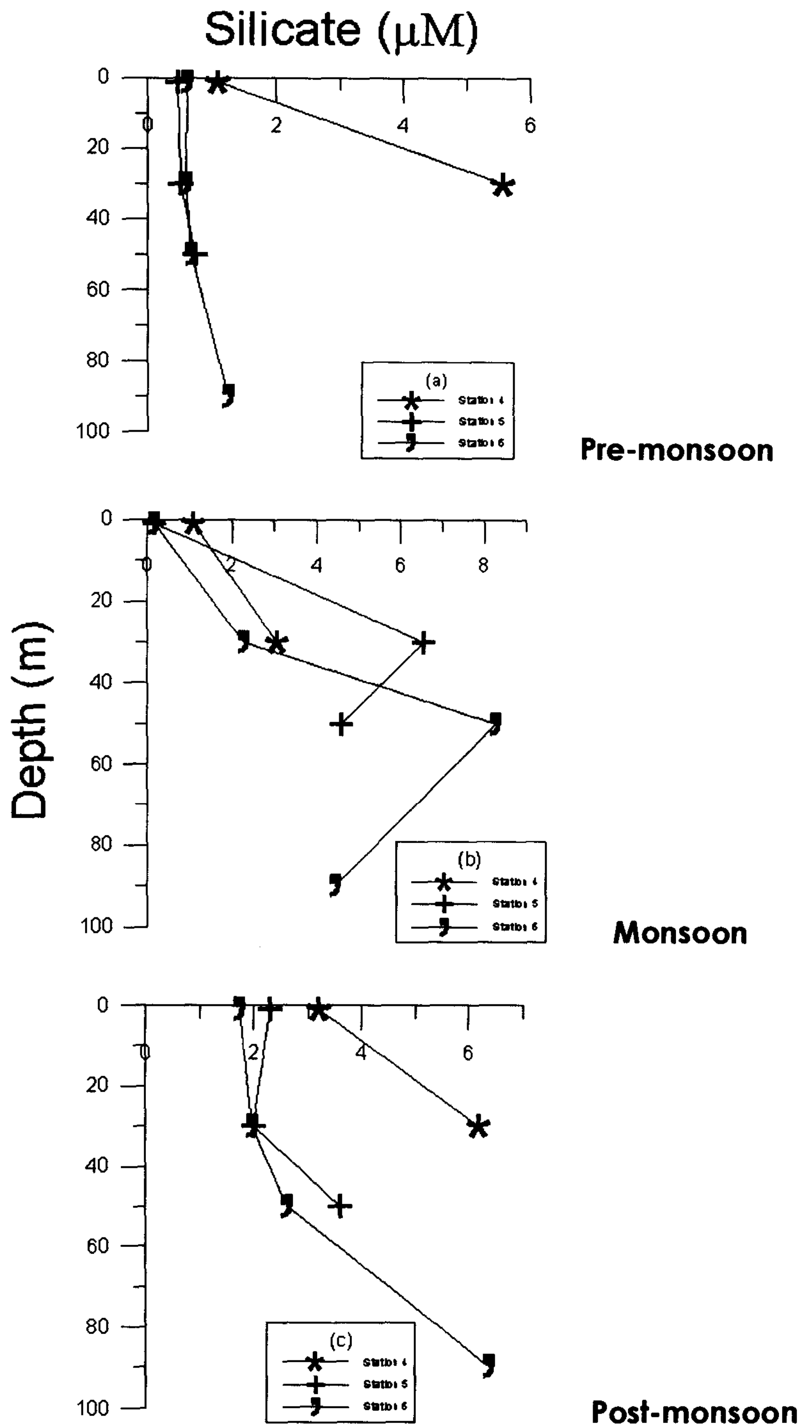


Fig. 4.12. Vertical distribution of Silicate along off Mangalore transect during different seasons

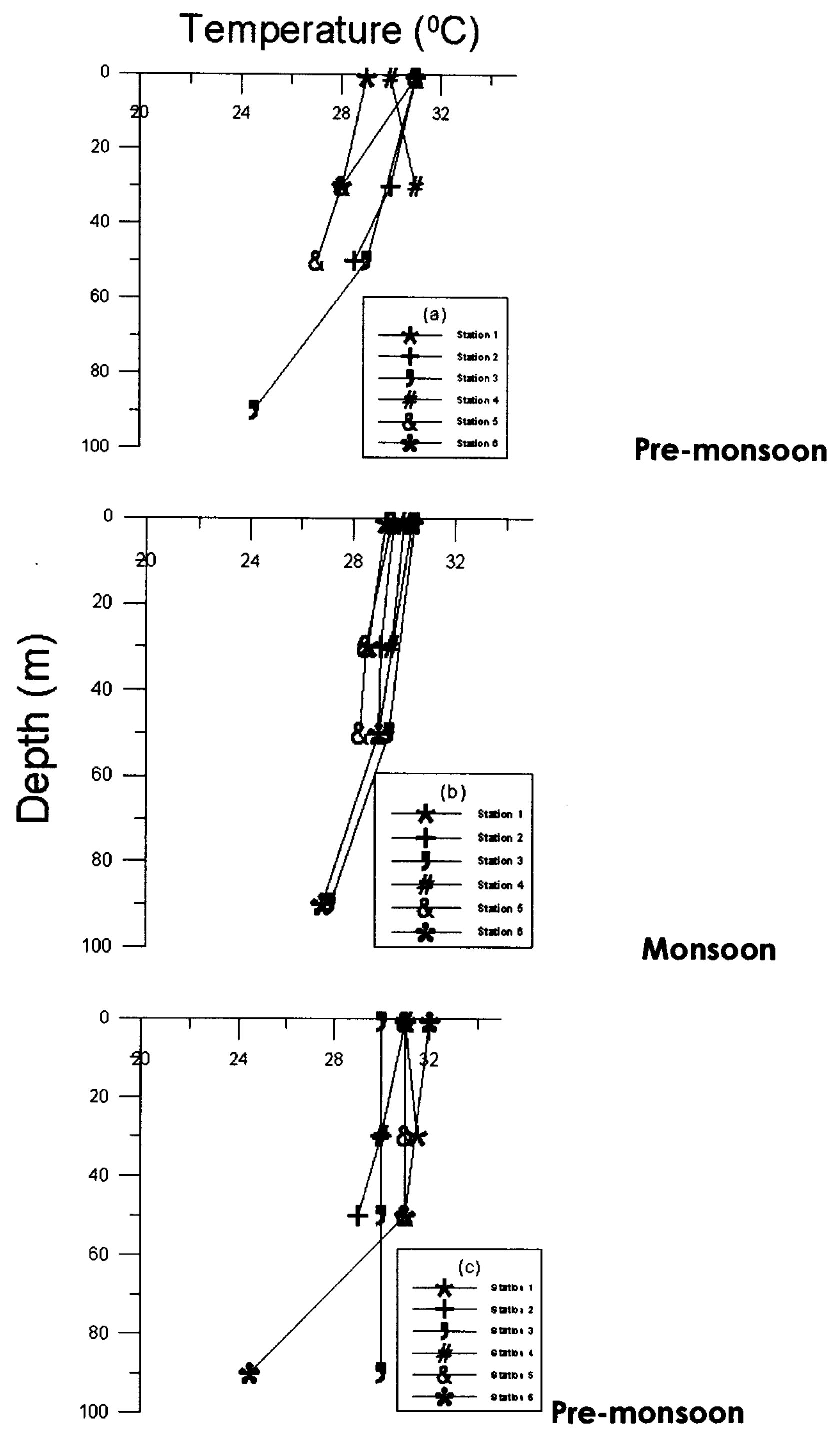


Fig. 4.13. Vertical distribution of Temperature along off Kakinada transect during different seasons

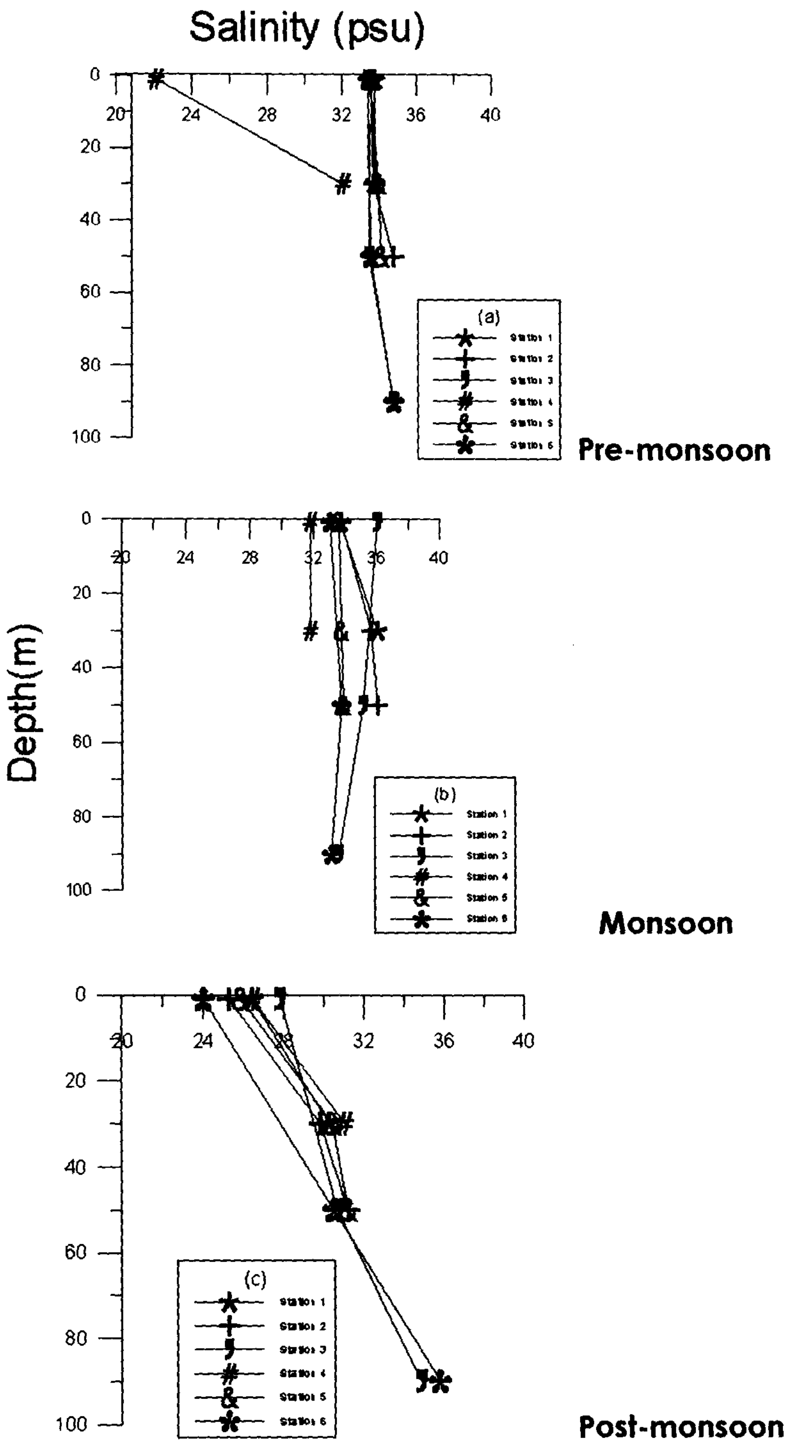


Fig. 4.14. Vertical distribution of Salinity along off Kakinada transect during different seasons

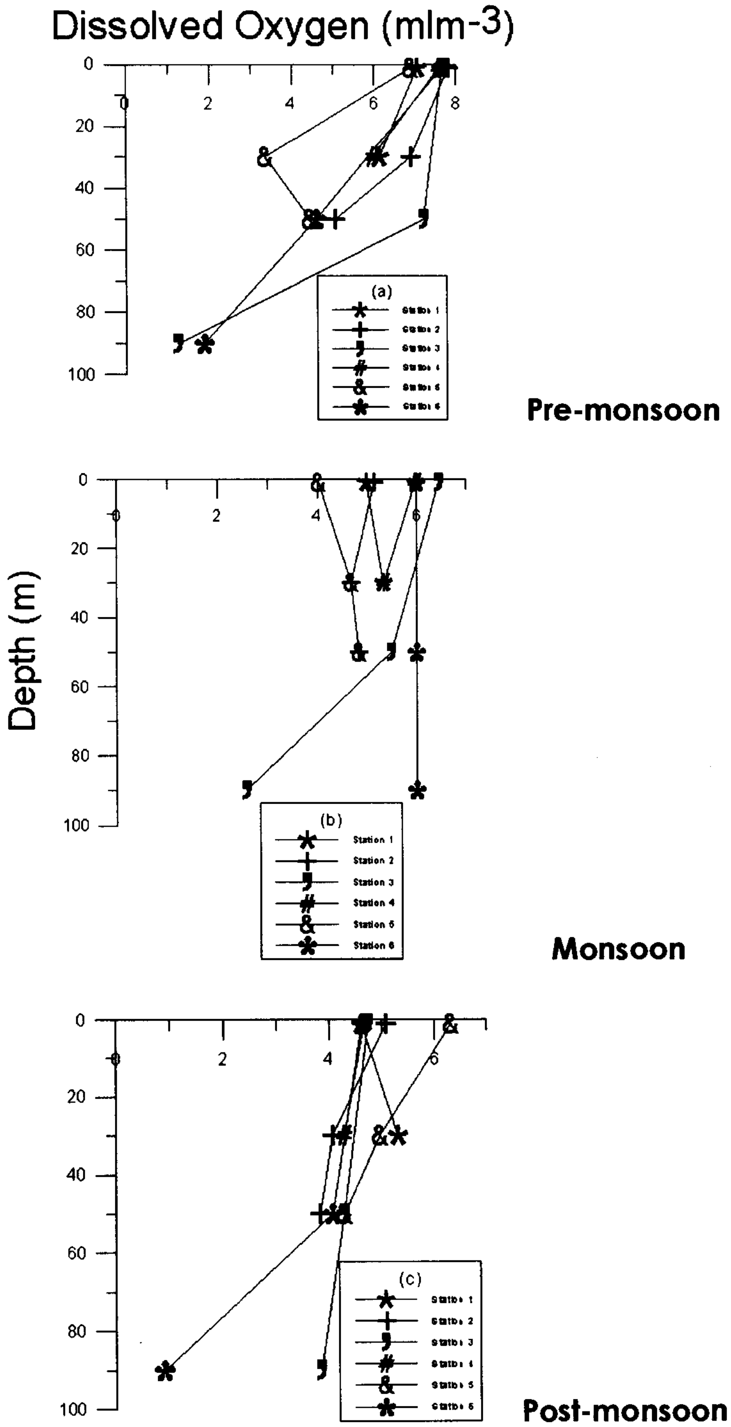


Fig. 4.15. Vertical distribution of Dissolved Oxygen along off Kakinada transect during different seasons

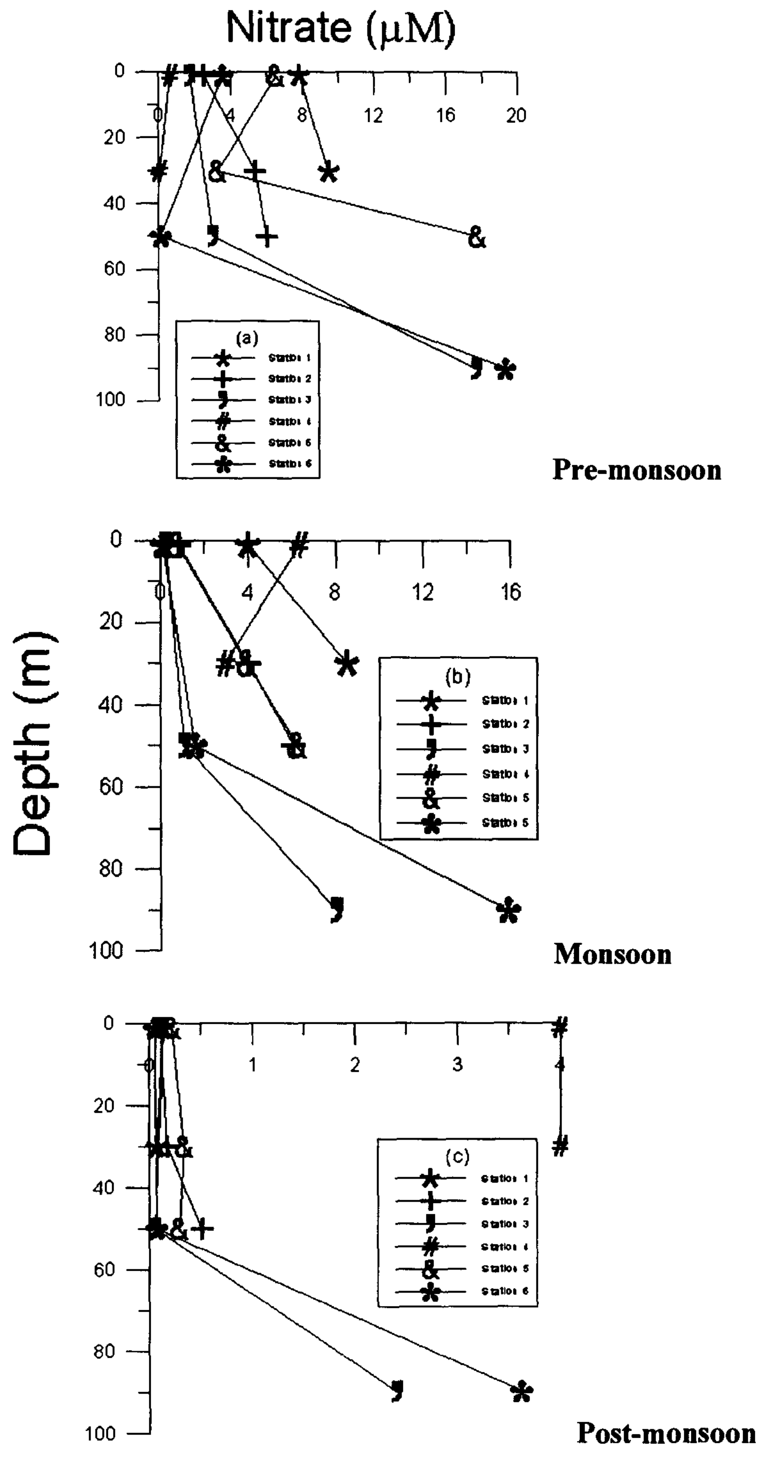


Fig. 4.16. Vertical distribution of Nitrate along off Kakinada transect during different seasons

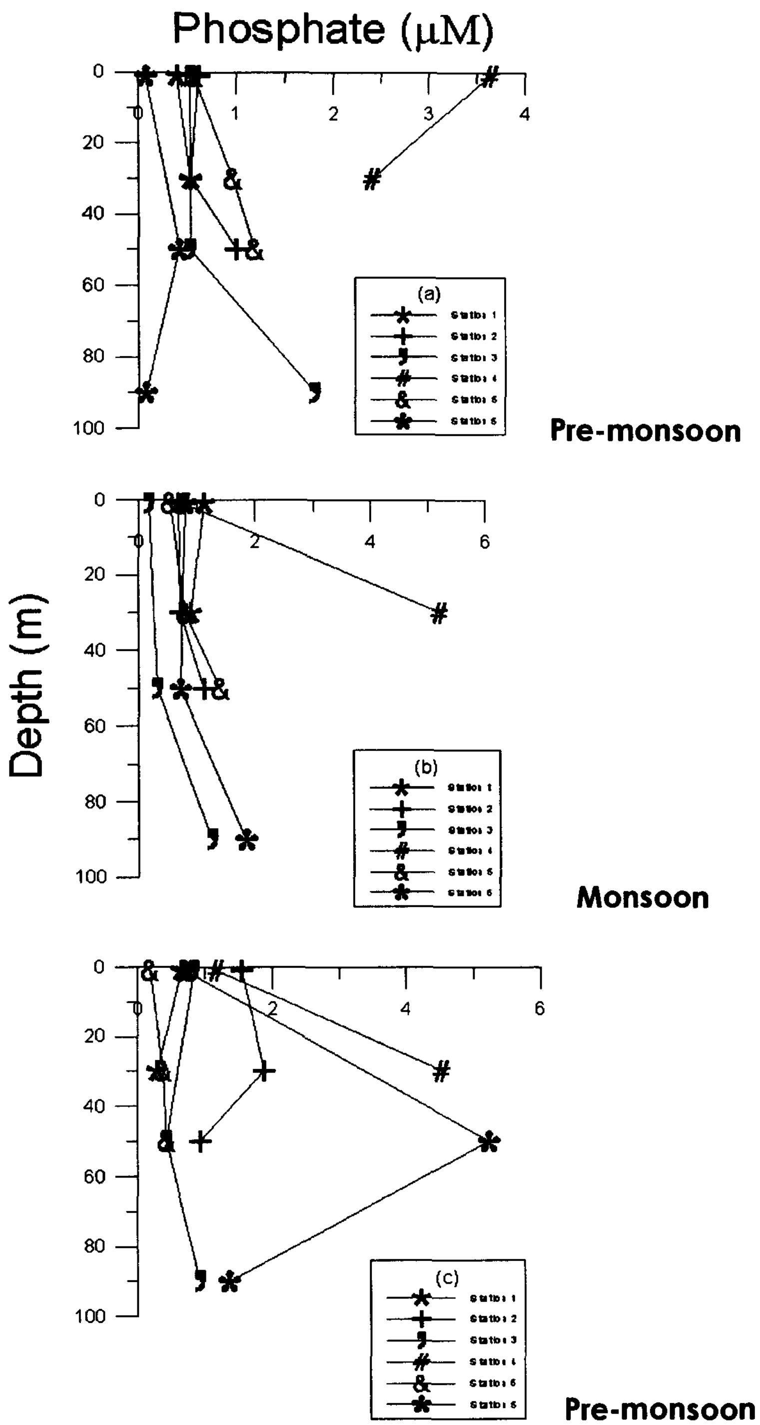


Fig. 4.17. Vertical distribution of Phosphate along off Kakinada transect during different seasons

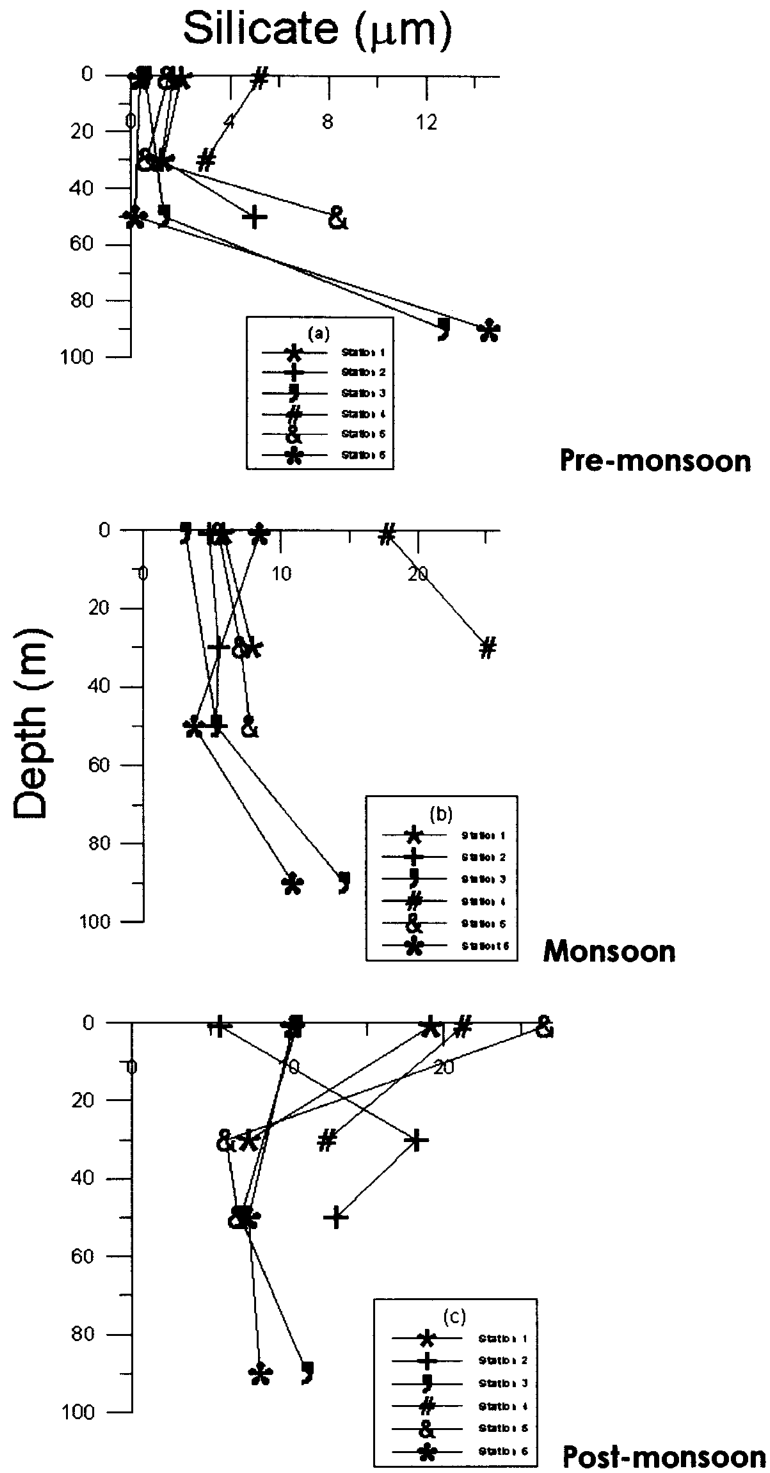


Fig. 4.18. Vertical distribution of Silicate along off Kakinada transect during different seasons

CHAPTER 5

Biological Parameters

5.1. West coast (off Goa and off Mangalore)

5.1.1. Chlorophyll *a*

Chlorophyll *a* was estimated as a measure of phytoplankton biomass. It ranged from 0.05 to 8.56 mgm^{-3} at the off Goa transect and 0.04 to 5.24 mgm^{-3} at the off Mangalore transect during the period of study. During pre-monsoon it ranged from 0.05 to 1.01 mgm^{-3}, while during monsoon the range was from 0.07 to 3.7 mgm^{-3} and during post-monsoon it varied from 0.1 to 1.55 mgm^{-3}, at the off Goa transect (Fig. 5.1 a-c). Off Mangalore transect, the ranges for the same period were 0.09 to 0.94 mgm^{-3} (pre-monsoon), 0.04 to 5.24 mgm^{-3} (monsoon) and 0.09 to 0.91 mgm^{-3} (post-monsoon) (Fig. 5.2 a-c). The highest values at both transects were observed during the monsoon season. Generally, at all the stations and during all the seasons, a sub-surface maxima was observed, mostly at 30 m depth and at some deeper stations, at 50 m depth. The highest values at both the transects recorded during the monsoon season were at 30 m of Stn. 4 (Fig. 5.3 b).

During the pre monsoon season an increasing trend was recorded with increasing depth at shallow stations at both transects. At deeper stations there was an overall decrease with depth generally below 50 m depth. Te overall trend showed that chlorophyll *a* content was higher at the off Goa stations compared to off Mangalore stations. The lowest value was recorded at 90 m depth of station 3 off Goa (0.05 mgm^{-3}) and at 50 m depth of station 6 off Mangalore (0.09 mgm^{-3}). The highest values recorded during the seasons where 1.01 mgm^{-3} (Stn. 1, 30 m) and 0.94 mgm^{-3} (Stn. 4, 30 m), in the above order. (Figs. 5.1 & 5.2)

Sub-surface maxima was quite conspicuous at both the transects, during the monsoon seasons also. During this season, at the shallow stations, such as Stns. 1 & 2 along the Goa transect, the highest Chl *a* values were recorded at 30 m depth (3.7 & 1.78 $mg.m^{-3}$), while at deeper station (Stn. 3), the maximum occurred at 50 m depth (0.98 $mg.m^{-3}$) (Fig. 5.1b). However, the near-surface value at Stn. 2 was also high (1.74 $mg.m^{-3}$), compared to the near-surface values of other stations at the Goa transect. A closely similar situation was observed at the Mangalore transect also. The sub-surface Chl *a* maxima was seen at 30 m depth at all the 3 stations (5.24, 0.51 and 0.77 $mg.m^{-3}$, at Stns. 4, 5 & 6 respectively. (Fig. 5.2 b). Here, even at the deeper station (Stn. 6, 100 m depth), the maximum was recorded at 30 m. The striking differences observed between the stations was that at Stn. 4, both near-surface and near-bottom (30 m) depths recorded high Chl *a* (2.56 & 5.24 $mg.m^{-3}$), respectively compared to other two stations in this transect. The lowest recorded values were 0.07 $mg.m^{-3}$ at Goa transect and 0.04 $mg.m^{-3}$ at Mangalore transect, and incidentally both at the deepest depth (90 m) of Stn. 3 and Stn. 6, respectively (Fig. 5.1b & 5.2b)

During the post-monsoon season also, the maximum Chl *a* values were recorded at all the stations in the sub-surface depths. The maximum values recorded at the off Goa transects were 0.77 (30 m), 1.55 (50 m) and 0.66 $mg.m^{-3}$ (100 m), at Stns. 1, 2 & 3, respectively (Fig. 5.1c). Along the off Mangalore transect the same were 0.91 (30 m), 0.72 (50 m) and 0.26 $mg.m^{-3}$ (100 m), at Stns. 4, 5 & 6, respectively (Fig. 5.2c). The lowest values recorded at these transects were 0.1 $mg.m^{-3}$ at off Goa transect and 0.09 $mg.m^{-3}$ at off Mangalore. A critical look at the values recorded in the different depth layers of the respective depth contours of the two transects for the study period indicates that the variations were narrow, except for the highest and the lowest values.

5.1.2. Mesozooplankton

5.1.2a. Biomass, diversity and abundance off the Goa coast

i] Pre-monsoon

Biomass values estimated for the three stations are shown in Fig. 5.3 a. The shallow stations recorded higher biomass (4.6 & 4.1 $ml.m^{-3}$ at Stn.1 (30 m) and Stn. 2 (50 m), compared to the deeper stations (2.1 $ml.m^{-3}$ at Stn. 3 (100m)).

A total of 21 groups of mesozooplankton were recorded during this season. The number of groups encountered were 15, 20 and 19 at Stns. 1 (30 m), 2 (50 m) and 3 (100 m) respectively. (Table 5.1). The groups generally consisted of copepods, chaetognaths, ostracods, stomatopods, oikopleura, doliolum, fish larvae, medusae, salps, gastropod larvae, bivalve larvae, euphausiids, *Lucifer* cladocerans, amphipods, polychaetes, siphonophores, Pteropods, foraminiferans, crustacean nauplii, decapods and echinoderm larvae. However, station-wise variations in composition was observed.

Copepods, ostracods, chaetognaths, gastropod larvae, bivalve larvae, pteropods, oikopleura, siphonophores, *Lucifer* and fish larvae were invariably present at all the stations and in higher numbers compared to the other groups along the Goa coast. Euphausiids, brachyuran zoea, amphipods, decapods foraminiferans and Echinoptus were present at the Stns. 2 & 3 (50 & 100 m). Polychaetes and cladocerans occurred in relatively higher numbers at the Stns. 1 & 2. Doliolum and medusae were relatively high in number at Stns. 1 & 3. However, some groups such as penaeid larvae (Stn. 1), crustacean nauplii and stomatopods (Stn. 2) and medusae and salps (Stn. 3) were encountered at one station each.

Total faunal density were 30986, 12869 and 5883 ind.m^{-3} respectively, at Stns. 1, 2 & 3 (Table 5.1). Copepod was the single largest group present at all the stations and its density was 13879, 8477 and 4781 ind.m^{-3} in the same order above, forming 45, 66 and 81% of the total density at the respective stations. This was followed by ostracods with a density of 11917, 1512 and 66 ind.m^{-3} and contributed to 38, 12 and 1%, of the population at Stns. 1, 2 & 3, respectively.

ii] Monsoon

An overall reduction in zooplankton biomass was observed during this season. The highest biomass recorded was 3.7 ml.m^{-3} at Stn. 1 (30 m), followed by Stn. 3 (100 m), 1.2 ml.m^{-3} and the lowest of 1 ml.m^{-3} at Stn. 2 (50 m) (Fig. 5.3 a).

During this season a total of 20 taxa/groups were collected which comprised of copepods, chaetognaths, ostracods, oikopleura, doliolids, fish larvae, fish eggs, medusae, salps, gastropod larvae, bivalve larvae, euphausiids, *Lucifer*, cladocerans, ctenophores, cirriped larvae, amphipods, polychaetes, siphonophoress, pteropods and decapods. The taxa/groups present at Stns. 1, 2 & 3 were 18, 17 & 15, respectively (Table 5.2).

Copepods, cladocerans, ostracods, oikopleurans, chaetognaths, medusae, siphonophores, doliolids, polychaetes, and fish larvae were common at all the stations and generally present in higher number, compared to the other groups. Salps, ctenophores, *Lucifer*, pteropods and cirriped larvae, brachyuran zoea and bivalve larvae were also present generally in high numbers, at some the stations. Gastropod and fish eggs were present only at Stns. 2 & 3. *Lucifer*, amphipods, brachyuran zoea, bivalve larvae, pteropods and oikopleurans, were present at the Stns. 1 & 2. Some groups such as ctenophores and cirripede larvae (Stn. 1), decapods (Stn. 2) and euphausiids (Stn. 3) were collected from only one station during this period.

At Stn. 1, the density (152748 ind.m^{-3})was almost five fold higher and at Stn. 2 (34839 ind.m^{-3}), three fold higher compared to that of premonsoon. but at Stn. 3, the density was marginally low (3355 ind. m^{-3}). Copepod density at Stn. 1 (30 m) was the highest (106685 ind.m^{-3}) and Stn. 2 (50 m) and Stn. 3 (100 m) also followed the similar trend (22279 and 2625 ind.m^{-3}, respectively.). During this season, cladocerans were the second abundant group compared oikopleurans. The density, however varied between stations, depending on the depth of stations. It was 24543, 3147 and 14 ind.m^{-3}, respectively at Stns. 1, 2 & 3 and contributed to 16, 9 and 0.4%, respectively to the total density of the stations.

iii] Post-monsoon

During this season biomass recorded were 4.3, 1.3 and 0.4 ml.m^{-3} at stations 1, 2 & 3, respectively (Fig. 5.3.a). As in the other seasons, the highest biomass was recorded at the shallower stations. During this season the lowest biomass for the period of study was also recorded at the deepest station (Stn.3, 100 m).

The maximum number of 22 taxa/groups of mesozooplankton were recorded during this season. The composition was 22, 19 and 21 groups at Stn 1 (30 m), Stn. 2 (50 m) and Stn. 3 (100 m), respectively (Table 5.3.). The groups included copepods, chaetognaths, ostracods, oikopleura, doliolids, fish larvae, medusae, salps, gastropod larvae, bivalve larvae, euphausiids, stomatoapods, cladocerans, mysids, ctenophores, amphipods, polychaetes, siphonophores, bryozoan larvae, phoronid, pteropods and other decapods.

Copepods, ostracods, oikopleura, chaetognaths, bivalve larvae, medusae, polychaetes, euphausiids, siphonophoress, pteropods, gastropod larvae, brachyuran zoea, doliolids and decapods were common to all the stations and occurred in relatively higher numbers compared to the other groups. Amphipods, megalopa larvae, *Lucifer* and fish larvae were also present in high numbers at a few stations. Ctenophores were present at Stns. 2 & 3. Stomatopod larvae (Alima stage) were present at Stns. 1 & 2. Amphipods, mysids, *Lucifer*, penaeid larvae, salps and fish larvae were also present at Stns. 1 & 2. Some groups such as megalopa larvae (Stn. 1), cladocerans, bryozoan larvae and phoronid larvae (Stn. 2) were collected rarely.

Total faunal density encountered were 13192, 8630 and 3717 ind.m^{-3}, respectively at Stns. 1, 2 & 3, which were lower compared to that of pre-monsoon and monsoon seasons. Copepod was the largest group collected from all the stations and the density was 8125, 7523 and 2495 ind.m^{-3} at Stns. 1, 2 & 3, respectively forming 62, 79 and 67% of the total density at these stations.

5.1.2b. Biomass, diversity and abundance at the off Mangalore coast

i] Pre-monsoon

Biomass recorded the highest values (7.0 ml.m^{-3}) at Stn. 5 (50 m), followed by (2.0 ml.m^{-3}) Stn. 6 (100 m) and the lowest (0.5 ml.m^{-3}) at Stn. 1 (30 m) (Fig. 5.3b).

The total number of taxa/groups collected during this season were higher (25) compared to all the seasons off the Goa transect and were represented by 17, 25 and 23 groups at Stns. 4, 5 & 6 respectively. (Table 5.4). The groups comprised of copepods, chaetognaths, ostracods, oikopleura, doliolids, fish larvae, fish eggs, invertebrate eggs, medusae, salps, gastropod larvae, megalopa larvae, bivalve larvae, mysids, euphausiids, *Lucifer*, cladocerans, ctenophore, amphipods, polychaetes, siphonophores, stomatopods, pteropods, foraminiferans, bryozoan larvae, echinoderm larvae and other decapods.

The common taxa/group present off the Mangalore transect were quite similar to that observed off the Goa coast. Copepods, ostracods, gastropod larvae, oikopleurans, doliolids, polychaetes, brachyuran zoea, chaetognaths, pteropods, siphonophoress, *Lucifer*, megalopa larvae and other decapods were the common and abundant ones at all the stations. Compared to the other groups salps, cladocerans, euphausiids and polychaetes also occurred in fairly large numbers, but not at all the stations. Medusae, euphausiids, salp, amphipods, mysid and fish larvae were present only at Stns. 5 & 6. Stomatopods were present at stations 4 & 5. Cladocera, fish eggs and foraminiferans were present at Stns. 4 & 6. Some groups were rare and collected only at one station, viz. ctenophore, penaeid larvae, bivalve larvae, bryozoan larvae and echinoderm larvae at Stn. 5 and invertebrate eggs at Stn. 6.

Total faunal density were 9776, 12553 and 8106 ind.m^{-3}, respectively at Stns. 4, 5 & 6 (Table 5.4). The density at Stns. 4 (30 m), was three fold lower than that observed for the same period in similar depth contour (Stn. 1) off the Goa coast. The density observed at Stn. 5 was more or less similar to Stn. 2 off the Goa (both 50 m depth contours). At Stn. 6, the number observed was marginally higher compared to Stn. 3 off the Goa transect. Copepod was the largest group present at all the stations and the density at the 30, 50 and 100 m depths was 7764, 5681 and 5848 ind.m^{-3}, respectively, forming was 79, 45 and 72% of the total density at the respective stations. As along the in off Goa transect, ostracods formed the second largest group and contributed to 38 % of the total density at 50 m depth.

ii] Monsoon

The highest biomass of this season and for the entire study period was recorded at Stn. 4 (7.1 ml.m^{-3}) (Fig. 5.3b). At Stn. 5 it, was 1.2 ml.$m^{-3}$and at Stn. 6, 0.4 ml.m^{-3}.

During this season a total number of 24 taxa/groups were recorded. The groups consisted of copepods, chaetognaths, ostracods, oikopleura, doliolids, fish larvae, fish eggs, medusae, salps, gastropod larvae, bivalve larvae, euphausiids, *Lucifer*, cladocerans, ctenophores, stomatopod larvae, invertebrate eggs, foraminiferans, bryozoan larvae, cumaceans, amphipods, polychaetes, siphonophores, pteropods and decapods. The group composition at stations 4, 5 & 6 were 17, 18 & 19, respectively (Table 5.5).

Copepods, ostracods, oikopleura, chaetognaths, *Lucifer*, euphausiids, polychaetes, siphonophores and fish larvae were the dominant ones at all the stations. Invertebrate eggs, cladocerans, gastropod larvae, siphonophores, bivalve larvae, doliolids, ctenophores, foraminiferans and medusae were present at some stations in relatively higher numbers. Amphipods, megalopa larvae and stomatopod larvae were present at Stns. 5 & 6. Cladocerans and foraminiferans were present at Stns. 4 & 5. Bivalve larvae, doliolids and invertebrate eggs were present at Stns. 4 & 6. Other groups such as ctenophores, salps and gastropod larvae (Stn. 4, 30 m), medusae, cumaceans, penaeid larvae and pteropods at (Stn. 5, 50 m) and brachyuran zoea, fish eggs, bryozoa and other decapods (Stn. 6, 100 m) occurred at one station only.

Total faunal density were 99547, 39572 and 14122 ind.m^{-3}, respectively at the Stns. 4, 5 & 6. All these values were higher compared to the same season off the Goa transect for the respective depth contour. Copepod was the largest group at all the stations and its density was 71634, 28086 and 11056 ind.m^{-3}, respectively, which was 72, 71 and 78% of the total density of the stations concerned. This is followed by oikopleura which was (13728, 9609 and 2541 ind.m^{-3}, respectively), contributing to 14, 24 and 18%, respectively at Stn. 4, Stn. 5 and Stn. 6, respectively. This was in contrast to the abundance of cladocerans during the same season off the Goa coast for the same season and ostracods, during the premonsoon season.

iii] Post-Monsoon

Biomass recorded during this period were (0.5, 1.3 and 0.7 $ml.m^{-3}$, respectively at Stns. 4, 5 & 6) which were the lowest compared to other two seasons. (Fig. 5.3b)

The highest taxa/groups (26) of mesozooplankton were recorded during this season. There were 21, 22 and 19 groups present at Stns. 4, 5 & 6, respectively. (Table 5.6). The groups comprised of copepods, chaetognaths, ostracods, oikopleura, doliolids, fish larvae, fish eggs, invertebrate eggs, medusae, salps, gastropod larvae, bivalve larvae, euphausiids, *Lucifer*, cirripede larvae, isopods, stomatopods, mysids, ctenophorans, amphipods, polychaetes, *Acetes,* siphonophores, bryozoan larvae, pteropods, pontelid larvae and other decapods.

The major groups such as copepods, ostracods, oikopleura, chaetognaths, bivalve larvae, medusae, polychaetes, euphausiids, *Lucifer*, siphonophores, pteropods, gastropod larvae and brachyuran zoea were present invariably at all stations. The composition was more or less similar to that of the Goa coast for this season. Bivalve larvae, other decapods, amphipods and ctenophore were also present in higher number at some stations. Penaeid larvae were present in very small numbers at Stns. 5 & 6. Stomatopods and bivalve larvae were present at Stns. 4 & 5. Amphipod, mysids and other decapods were present at Stns. 4 & 6. Groups such as ctenophores, fish larvae and fish eggs (Stn. 4), cirriped larvae, *Acetes*, megalopa larvae, invertebrate eggs, pontelid larvae and bryozoan larvae (Stn. 5) and isopods and salps (Stn. 6) were confined to one station only.

Total faunal density was low (50894, 5632 and 7199 $ind.m^{-3}$ at Stns. 4, 5 & 6, respectively) compared to pre-monsoon and monsoon seasons. During this season also copepod formed the largest group at all the stations. Its density was 3562, 5086 and 5565 $ind.m^{-3}$ at Stns. 4, 5 & 6, respectively, forming 70, 90 and 77% of the total density. This was followed by oikopleura and ostracods contributing, 6.1, 0.3 & 7.2% and 1.7, 4.1 & 2.6 of the total density at Stns. 4, 5 & 6, respectively.

5.2. East Coast of India

5.2.1. Chlorophyll *a*

Chlorophyll *a* ranged from 0.04 to 0.82 $mg.m^{-3}$ along the off Kakinada coast during the study period. It ranged from 0.06 to 0.82 $mg.m^{-3}$ during the pre-monsoon, 0.05 to 0.67 $mg.m^{-3}$ during monsoon and 0.11 to 0.78 $mg.m^{-3}$ during the post-monsoon (Fig. 5.4 a-c). The range in variation between seasons was marginal, but the values were generally lower compared to those recorded along the west coast transects.

One of the striking difference noticed was that the sub-surface maxima seen along the west coast transects were not visible here. Generally, the chl *a* content was relatively higher at near-surface or mid depth layers. The highest values for the season were recorded at near-surface layers of Stns. 5 (0.82 $mg.m^{-3}$), Stn. 1 (0.69 $mg.m^{-3}$) and Stn. 2 (0.43 $mg.m^{-3}$). The lowest values recorded were at the deepest layers, (100 m) of Stns. 3 & 6 (both 0.06 $mg.m^{-3}$) (Fig. 5.4 a). At shallow depths, the chlorophyll distribution was found to be somewhat uniform at all the shallow stations, compared to deeper stations where there was a sudden drop could be seen.

During the monsoon season, the range in chl *a* content was 0.04 – 0.67 $mg.m^{-3}$ (Fig. 5.4 b). No sub-surface maximum was discernable at any station during this period also. Generally, the shallow stations had relatively higher values at the near-surface waters than mid-depth region. The highest values recorded during this season was in the near-surface layers at Stn. 6. (0.67 $mg.m^{-3}$), Stn. 4 (0.60 $mg.m^{-3}$) and Stn. 3 (0.57 $mg.m^{-3}$). Incidentally at Stn. 3, the 100 m layer also recorded fairly higher values (0.57 $mg.m^{-3}$), although the 100 m layer at Stn. 6 recorded the lowest value (0.04 $mg.m^{-3}$) for this season (Fig. 5.4 b)

Chlorophyll distribution during the post-monsoon season appears to be generally higher, both spatially and vertically. The range observed was between 0.11 and 0.78 $mg.m^{-3}$ (Fig. 5.4 c). During this season also, the near-surface layers at most of the stations, recorded the highest values, except at Stns. 1 & 3, where the near-bottom layers showed maximum chl *a* content (0.78 $mg.m^{-3}$ & 0.70 $mg.m^{-3}$ respectively). The highest values recorded for near-surface were 0.66 (Stn. 6), 0.60 (Stn. 5) and 0.53 $mg.m^{-3}$ (Stn. 1) (Fig. 5.4c)._However, no sub-surface maximum was observed at any stations during this season also.

5.2.2. Mesozooplankton

5.2.2a. Biomass, diversity and abundance off Kakinada coast

i] Pre-monsoon

Biomass ranged from 0.17 $ml.m^{-3}$ to 0.78 $ml.m^{-3}$ during this season. (Fig. 5.5). The highest was recorded at Stn. 4 (30 m depth) and the lowest at Stn. 3 (100 m depth). Except for the highest value, the range was between 0.17 and 0.34 $mg.m^{-3}$. The biomass recorded along this coast were lower compared to those recorded along the west coast transects during the season.

Overall 19 taxa/groups were recorded during this period from the entire study area. At 30 m stations, viz. Stns. 1 & 4, 12 & 13 groups were recorded. At 50 m depth (Stns. 2 & 5)17 and 15 groups, respectively were collected. The number of groups present at 100 m stations, i.e., 3 & 6 were 16 & 14, respectively (Table 5.7). The mesozooplankton groups consisted of siphonophores, ctenophores, polycheates, copepods, cladocerans, ostracods, amphipods, euphasiids, decapods, stomatopods, chaetognaths, bivalve larvae, gastropod larvae, pteropods, oikopleura, salps, doliolids, fish eggs and fish larvae. The number of groups/taxa encountered were generally low compared to the same season and respective depth contours along the west coast transects.

Copepod, chaetognath, decapods, fish eggs and ostracods were the dominant groups present at all the stations. Copepod was the most abundant group during this season. This was followed by chaetognaths, siphonophores, polychaetes, pteropod, oikopleura, salps, doliolids and fish larvae which occurred at nearly all the stations. Medusae, amphipods and stomatopod larvae were present only at a few stations while ctenophores, euphasiids, bivalve larvae and gastropod larvae were rare during this season.

Zooplankton density varied from 197 to 565 ind.m^{-3}. At Stns. 1 & 4 (30 m) the density was 564 & 414 ind.m^{-3}, while at Stns. 2 & 5(50 m) it was 519 & 412 ind.m^{-3}, respectively. The lowest densities of 311 & 197 ind.$m^{-3}$for this season was recorded at the 100 m stations, at Stns. 3 & 6, respectively.

However, the faunal density recorded along the Kakinada coast was relatively low during this season as compared to the other two seasons. It was also several fold lower compared to that along both transects of the west coast for all the three seasons.

Copepod density ranged from 122 to 437 ind.m^{-3} at these stations which accounted for 69 & 73% at stations 1 & 4, 84 & 63% at stations 2 & 5 and 83 & 62% at stations 3 & 6, respectively.

ii] Monsoon

During this season zooplankton biomass ranged from 0.5 ml.m^{-3} (Stn. 6) to 5.5 ml.m^{-3} (Stn. 5). High biomass was generally recorded at shallow stations (30 & 50 m) compared to deeper stations (100 m). Both Stns. 3 & 6 which were at 100 m contour, registered biomass values of 0.9 and 0.5 ml.m^{-3} (Fig. 5.5)

Twenty five taxa/groups were recorded during this period. Fourteen groups were common at all the stations. They were, copepods, chaetognath, bivalve larvae, oikopleura, decapods, ostracods, pteropods, gastropod larvae, siphonophores, polychaetes, amphipods, fish larvae, salps and stomatopods. (Table 5.8). Of these copepods, chaetognaths, bivalve larvae, oikopleura, decapods, ostracods, pteropods, gastropod larvae, siphonophores, polychaetes and amphipod were the dominant ones. *Acetes* and medusae were recorded in higher numbers at Stns. 3, 4 & 5. Doliolids and fish eggs were present at few stations while ctenophores, cladocerans, mysids, euphasiids, cirripede larvae, bryozoan larvae and echinoderm larvae were present only at one or two stations.

Total faunal density ranged from 6909 to 44229 ind.m^{-3} during this season which was the highest compared to the other seasons. It was 14794 & 44229 ind.m^{-3}at Stns. 1 & 4 (30 m), 6906 & 8078 ind.m^{-3} at Stns. 2 & 5 (50 m) and 7699 & 6909 ind.m^{-3}at Stns. 3 & 6 (100 m), respectively (Table 5.8). Copepod contributed to 95 & 87% density at Stns. 1 & 4, 64 & 84% at Stns. 2 & 5 and 94 & 87% at Stns. 3 & 6, respectively. Chaetognath contributed to 25.5% at Stn. 2 while it varied between 1 and 4% at other stations.

iii] Post-monsoon

Biomass varied from 0.28 to 0.98 ml.m^{-3} during the post-monsoon season, the lowest being at Stn. 4 (30 m) and the higher being at Stn. 1 (30 m) (Fig. 5.5). Biomass was 0.98 & 0.28 ml.m^{-3} at the 30 m (Stns. 1 & 4), 0.51 & 0.4 ml.m^{-3} at 50 m (Stns. 2 & 5) and 0.4 at the 100 m (Stn. 3 & 6), respectively.

On the whole, 24 zooplankton taxa/groups were represented in the samples during this season, viz. copepods, oikopleura, chaetognaths, siphonophores, medusae, ctenophore, polychaetes, cladocerans, ostracods, amphipods, mysids, euphausiids, decapods, stomatopods, gastropods, cephalopods, heteropods, pteropods, salps, doliolids, fish egg, fish larvae, amphioxus and pyrosoma (Table 5.9). Out of these copepods, oikopleura, chaetognaths, siphonophores, medusae, polychaetes, amphipods, decapods, pteropods and doliolids were encountered at all stations. Only three groups, viz copepods, oikopleura and chaetognaths dominanted the community. Heteropods, fish larvae and amphioxus were present nearly at all stations. Ctenophores, cladocerans, ostracods, mysids, euphausiids, stomatopods, gastropods, cephalopods, salps, fish eggs and pyrosoma were present at one or two stations only.

Total faunal density ranged from 955 to 3439 ind.m^{-3} during this season. Density was 2151 & 955 ind.m^{-3} at the 30 m stations, viz. 1 & 4, 1421 & 2753 ind.m^{-3} at the 50 m (Stns. 2 & 5) while it was 3439 & 1195 ind.m^{-3} at the 100 m (Stns. 3 & 6), respectively (Table 5.9). Copepod contributed to 84 & 93% at the Stns. 1 & 4, 90 & 91% at Stns. 2 & 5 and 93 & 82% at Stns. 3 & 6, respectively. Oikopleura contributed to 10% at Stn. 6, 7% at Stn. 1 and 3% at Stns. 2, 3, 4 & 5).

5.3 Statistical Analyses

The zooplankton taxa/group density of both the coasts were subjected separately to Bray-Curtis Analysis for each season to identify the Similarity clusters formed by the stations for the study area. They were also further grouped by non-metric multi-dimensional scaling (MDS). Later the data was subjected to SIMPER Analysis.

5.3.1 Zooplankton along the Goa and Mangalore coasts (west coast)

1] Pre-monsoon

Bray-Curtis analysis revealed two groups for the entire study area during premonsoon (Fig. 5.6a), the first one being Stns. 3, 5, & 6 with 68.13% similarity and second group consisted of Stns. 2 & 4 with 73.7% similarity. Station 1 did not cluster with any of the above. A similar grouping was seen in the MDS diagram. (Fig. 5.6b)

SIMPER analysis was performed so as to recognise the zooplankton groups that contributed to the dissimilarity between the identified clusters. Groups 3 & 2 were dissimilar (50.89%) and ostracods, copepods, polychaetes, cladocerans and gastropod larvae were some of the major groups responsible for (Table 5.10) the differences between the groups.

Groups 1 & 3 showed 60.97% dissimilarity, the major groups of zooplankton responsible for this were ostracods, copepods, polychaetes, cladocerans and other decapods.

Groups 2 & 1 showed 34.37% dissimilarity. Groups contributing to the dissimilarity were copepods, ostracods, gastropod larvae, oikopleura, other decapods, cladocerans, salps, bivalve larvae, foraminiferans and pteropods.

2] Monsoon

During this season, Bray-Curtis analyses divided the study area into two groups (Fig. 5.7a), the first one was formed with Stns. 2 & 5 (Group 1) and the second one with Stns. 1 & 4 (Group 2). Stns. 3 & 6 did not cluster with any of the above groups and MDS confirmed the grouping observed in cluster analysis (Fig. 5.7b).

The major groups of zooplankton that contributed to the dissimilarity (55.54%) between the groups 1 & 2 were copepods, cladocerans, oikopleura and invertebrate eggs.

Groups 2 & 4 were dissimilar (94.89%) due to copepods, cladocerans, oikopleura and invertebrate eggs.

Groups 1 & 4 were dissimilar as copepods, oikopleura and cladocerans contributed to the differences with 84.05%.

Groups 2 & 3 showed 79.30% dissimilarity and was contributed by copepods, cladocerans, oikopleura and invertebrate eggs.

The group 1 & 3 showed 45.67% dissimilarity. The groups which contributed to the dissimilarity were copepods, oikopleura, cladocerans and polychaete

The last group 3 & 4 showed 64.35% dissimilarity. Copepods and oikopleura, contributed to the dissimilarity. (Table 5.11)

3] Post-monsoon

Two groups (Fig. 5.8a) were identified for the study area during this season which comprised Stns. 2, 5 & 6 with 75.98% similarity and Stns. 3 & 4 with 73.2% similarity. Stns. 1 did not cluster with any of the groups. A similar grouping was seen in the MDS (Fig. 5.8b). Dissimilarity (34.42%) observed (SIMPER analysis) between groups 1 & 2 were due to-amphipods, copepods, oikopleura, chaetognaths, megalopa, medusae, siphonophores and *Lucifer*.

Group 2 & 3 indicated 55.91% dissimilarity as a result of copepods , amphipods, oikopleura and megalopa.

Groups 1 & 3 showed dissimilarity of 37.00%. The groups which contributed to the dissimilarity were copepods , oikopleura , chaetognaths , ostracods, siphonophore , pteropods, bivalve larvae and *Lucifer*. (Table 5.12)

5.3.2 Zooplankton along the Kakinada coasts (east coast)

1] Pre-monsoon

Bray-Curtis analysis categorized the study area into three groups (Fig. 5.9a). The first group consisted of Stns. 3, 4 & 5 with 70.52% similarity. The second group was formed by Stns. 1 & 2 and showed 75.2% similarity. Station 6 did not cluster with any of the groups. A similar grouping was seen in the MDS (Fig. 5.9b).

SIMPER analysis showed that contributed groups 1 and 2 were dissimilar (34.10%) owing to the difference in the contribution of copepods, chaetognaths, oikopleura, medusae, siphonophores, bivalve larvae and gastropod larvae at these stations.

Similarly, groups 2 and 3 showed 56.34% dissimilarity which was due o four groups, viz. copepods, chaetognaths, oikopleura and siphonophores. (Table 5.13)

Groups 1 and 3 showed 45.35% dissimilarity. The groups which contributed to the dissimilarity were copepods (57.69%), medusae (10.72%), oikopleura (8.23%), gastropod larvae (5.06%), siphonophores (4.44%), Fish eggs (3.47%) and chaetognaths (3.30%)

2] Monsoon

Only one cluster, comprising of Stns. 2, 3, 5 & 6 with 69.03% similarity was found with Bray-Curtis analysis. Station 1 & 4 did not form a cluster with any of the groups (Fig. 5.10a). A similar grouping was seen in the MDS (Fig. 5.10b).

SIMPER analysis showed dissimilarity between groups 1 & 2 (41.31%) which was caused by the uneven abundance of copepods and chaetognath at these stations.

Groups 2 & 3 showed 50.27% dissimilarity due to copepods, chaetognaths, bivalve larvae and oikopleura

Groups 1 & 3 showed 72.01% dissimilarity. The groups which contributed to the dissimilarity were copepods and bivalve larvae. (Table 5.14)

3] Post-monsoon

Two distinct groups (Fig. 5.11a) were observed during this season. The first group consisted of Stns. 1, 3 & 5 with 77.91% similarity. The second group was formed by Stns. 2, 4 & 6 and showed 82.65% similarity. A similar grouping was seen in the MDS (Fig. 5.11 b).

The dissimilarity observed between group 1 & 2 was due to copepods and oikopleura. (Table 5.15)

CCA analysis

Canonical Correspondence Analysis (CCA) of station and group biplots were plotted, separately for west and east coast (Figs. 5.12 & 5.13). Five and four axes extracted for west and east coasts respectively.

In the CCA biplots for the west coasts, 5 axes explaining 91.88% of the relationship between zooplankton groups and environmental variables were extracted. Chlorophyll *a*, dissolved oxygen and silicate were the main environmental variables influencing the zooplankton groups along the west coast. Seasonal variation were not clearly evident (Fig. 5.12a)

Along the east coast, 4 axes explained 91.79% of the relationship between zooplankton groups and environment variables. Temperature, dissolved oxygen and salinity were the most important environmental variables influencing the distribution of zooplankton groups. (Fig. 5.13.b). Station biplot indicated clear seasonal variations. (5.12.b). The zooplankton group codes are given in Table 5.16.

5.4 Systematic

The zooplankton samples collected were identified to major taxa/group level. In all 33 taxa were encountered in the present study. The systematic position of the zooplankton groups recorded from the east and west coasts of India are as follows:

Taxon **Systematic position**

1. Siphonophore

Phylum: Coelenterata

Class: Hydromedusae

Order: Siphonophora

2. Medusae

Phylum: Coelenterata

Class: Hydromedusae

3. Ctenophore

Phylum: Ctenophora

Class: Tentaculata

Order: Cydipida

Sub Order: Lobada

4. Polychaete

Phylum Annelida

Class Polychaeta

Family Aphroditidae

Family Magelonidae

Family Qweniidae

Family Pectinarridae

Family Spionidae

Family Syllidae

Family Terebellidae

Family Tomopteridae

Copepods

Phylum Arthropoda

Class Crustacea

Subclass Copepoda

Order Calanoida

Order Cyclopoida

Order Harpacticoida

5. Cladocerans

Phylum: Arthropoda

Class: Crustacea

Sub Class: Brachiopoda

Order: Cladocera/Onchypoda

6. Ostracods

Phylum: Arthropoda

Class: Crustacea

Sub Class: Ostracoda

7. Cirripede larvae

Phylum Arthropoda

Class Crustacea

Subclass Thecostraca

Super Order Cirripedia

8. Amphipods

Phylum: Arthropoda

Class: Crustacea

Subclass Malacostraca

Order: Amphipoda

Sub Order: Hyperidae

9. Isopods

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Isopoda

10. Cumaceans

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Cumacea

11. Mysids

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Mysidacea

12. Euphasiids

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Euphausiiacea

13. Acetes

Phylum: Arthropoda

Class: Crustacea

Subclass Malacostraca

Order: Decapoda

Family: Surgestidae

Genus: Acetes

14. Lucifer

Phylum: Arthropoda

Class: Crustacea

Subclass Malacostraca

Order: Decapoda

Suborder: Natantia

Family: Sergestoidea

Genus: Lucifer

15. Penaeids

Phylum: Arthropoda

Class: Crustacea

Subclass: Malacostraca

Order: Decapoda

Subfamily: Penaeoidae

Family: Penaeidae

16. Brachyurian zoea

Phylum: Arthropoda

Class: Crustacea

Subclass: Malacostraca

Order: Decapoda

Infraorder: Brachyura

17. Porcellanid Zoeae

Phylum: Arthropoda

Class: Crustacea

Order: Decapoda

Infraorder: Anomura

18. Megalopa stage

Phylum: Arthropoda

Class: Crustacea

Subclass: Malacostraca

Order: Decapoda

Infraorder: Brachyura

19. Other decapods

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Decapoda

Section/Super Order Caridea

Section/Super Order Anomura

Section/Super Order Brachyura

Section/Super Order Macrura

20. Stomatopods

Phylum: Arthropoda

Class: Crustacea

Order: Stomatopoda

21. Chaetognaths

Phylum Chaetognath

Class Sagittoidea

Order Sagitta

22. Bivalve larvae

Phylum: Mollusca

Class: Bivalvia (Bivalve)

23. Gastropod larvae

Phylum: Mollusca

Class: Gastropoda

Order: Heteropoda

Sub Order: Janthiniidae

24. Pteropods

Phylum: Mollusca

Class: Gastropoda

Sub Class: Opisthobrachia

Order: Pteropoda

Genus: Creseis

25. Oikopleura

Phylum: Urochordata

Class: Appendicularia

Order: Urochordata

Family: Oikopleuridae

Genus: Oikopleura

26. Salps

Phylum: Urochordata

Class: Thaleacea

Order: Desmomyaria

Family: Salpidae

Genus: Salpa

Doliolum

Phylum: Eurochordata

Class: Thaliacea

Order: Cyclomyaria

Family: Doliolidae

Genus: Doliolum

27. Fish eggs

Phylum: Chordata

Class Osteichthyes,

Type: Fish eggs

28. Fish Larvae

Phylum: Chordata

Class Osteichthyes,

Type: Fish larvae

29. Foraminiferans

Phylum: Protozoa

Class: Sacrodina

Sub Class: Rhizopoda

Order: Foraminifera

30. Bryozoan larvae

Phylum Ectoprocta

Class Gymnolaemata

Order Cheilostomata

Type Bryozoan larvae

31. Echinoderm larvae

Phylum Echinodermata

5.5 Trophic relationship

In order to understand the energy available at the primary trophic level (phytoplankton) and the energy requirement at the secondary trophic level (zooplankton) in the study area along the east and west coasts, the phytoplankton biomass (Chl *a*) and the zooplankton biomass were converted to respective carbon equivalent for each study area, separately for each season, using the conversion coefficients as given in the Material and Methods. For the west coast, the biomass data obtained for off Goa and off Mangalore transects were pooled so as to represent the study area along the west coast.

The phytoplankton and zooplankton biomass were calculated for the study area on the seasonal basis and annual basis, by taking into account the total area studied along the east and west coasts. Biomass was also determined for the water column of the study area, seasonally and annually. For this purpose, the biomass values collected for the upper 50 m water column was only considered since below this depth productivity was generally low.

5.5.1. West Coast

Accordingly, the biomass of phytoplankton calculated for the study area was 48.5 $KgC.m^{-2}$ for the pre-monsoon season and 54.5 $KgC.m^{-2}$ for the post-monsoon season. However for the monsoon season the biomass was 2429.9 $KgC.m^{-2}$, which was 40 folds that of the other two seasons. The annual contribution was calculated to be 844.3 $KgC.m^{-2}$. When the biomass values were calculated for the volume of water for the study area, the seasonal values obtained were 2.42 and 2.7 $KgC.m^{-3}$ for the pre-monsoon and post-monsoon seasons respectively, while the same for the monsoon season was 121.5 $KgC.m^{-3}$ (Fig. 5.14 a) which is >50 times the other two seasons. When the biomass values were converted on an annual basis, the quantum of carbon was estimated to be 42.2 $KgC.m^{-3}$.

The seasonal variation in mesozooplankton biomass for the entire study area calculated in terms of carbon was 1973.2 $KgC.m^{-2}$ for the pre-monsoon season. 1419.1 $KgC.m^{-2}$ for the monsoon season and 826.2 $KgC.m^{-2}$ for the post-monsoon. This was in contrast to the phytoplankton biomass, which recorded high value only during the monsoon. The annual biomass was estimated to be 1406.2 $KgC.m^{-2}$.

For the water column, the zooplankton biomass estimated for the seasons were, 98.6 $KgC.m^{-3}$ for the pre-monsoon season, 70.9 $KgC.m^{-3}$ for the monsoon season and 41.3 $KgCm^{-3}$ for the post-monsoon season (Fig. 5.14 a). The annual contribution of zooplankton carbon for the 50 m water column of the study area was estimated to be 70.3 $KgC.m^{-3}$.

It can be seen from the biomass values available for the different seasons that autotrophy was prevalent along the west coast only during the monsoon season when mesozooplankton could sustain the energy requirement through phytoplankton biomass since the phytoplankton biomass available exceeded the energy requirement of zooplankton. However, during pre-and post-monsoon seasons, a different picture has been depicted (Fig. 5.14 a). Here the available zooplankton carbon (98.6 and 41.3 $KgC.m^{-3}$) far exceeded the availability of phytoplankton biomass and therefore mesozooplankton may be feeding on available alternative food sources such as microzooplankon, since the phytoplankton biomass prevailing was not sufficient to sustain the zooplankton biomass. The results thus indicate that the autotrophy was prevailing only during the monsoon, while during the pre- and post-monsoon seasons, heterotrophy was more common. In other words, it was only during the monsoon season that phytoplankton biomass was available in excess to support the requirement of zooplankton standing stock. During the other two seasons, the phytoplankton biomass was insufficient to sustain the zooplankton biomass and therefore, the latter had to feed on other sources such as attached bacterioplankton, microzooplankton or suspended organic matter etc. whichever was available.

5.5.2 East Coast

Along the east coast, the phytoplankton biomass estimated for the study are during different seasons were as follows: pre-monsoon- 79.3 $KgC.m^{-2}$, monsoon- 77.4 $KgC.m^{-2}$ and post-monsoon- 85.7 $KgC.m^{-2}$. The variations between the seasons were found to be marginal. The biomass values obtained were in contrast with that of the west coast in that during both pre- and post-monsoon it recorded higher values, but during the monsoon season the estimated value for the east coast was far too small as compared to that of the west coast. The annual contribution estimated was 80.8 $KgC.m^{-2}$ which was 10 times lower than that of west coast. When the values were calculated for the upper 50 m water column, a uniform pattern was noticed for the seasons. It was 3.9 $KgC.m^{-3}$ for pre-monsoon, 3.8 $KgC.m^{-3}$ for monsoon and 4.3 $KgC.m^{-3}$ for post-monsoon seasons. (Fig 5.14 b). Although these values during the pre- and post-monsoon were slightly more than those of the west coast, the monsoon season biomass was ~30 folds lower than that of the west coast. The annual biomass production was calculated to be 4.04 $KgC.m^{-3}$, which was also about 10 times lower than that of the west coast.

The zooplankton biomass when computed for the study area on a seasonal basis, the carbon equivalent obtained were 94.0. 2055.7 and 144.2 $KgC.m^{-2}$, respectively for pre-monsoon, monsoon and post-monsoon seasons. The annual biomass production was to the tune of 764.7 $KgCm^{-2}$. Except that of the monsoon biomass, the values obtained for the other two seasons were lower compared to that of the west coast. The biomass values estimated for the water column for these seasons were 4.7, 102.8 and 7.2 $KgC.m^{-3}$, respectively (Fig. 5.14 b) in the above mentioned order. The biomass sustained on an annual basis was 38.2 $KgC.m^{-3}$ which is almost half that of the west coast. In this case also the monsoon biomass recorded was significantly higher compared to the west coast.

A contrasting trophic relationship could be observed along the east coast as compared to the west coast. Here, autotrophic relationship was not observed during any season, but heterotrophic relationship was prevailing during all the seasons. Although the extent was low during the pre- and post-monsoon, it was conspicuously high during the monsoon season (Fig. 5.14 b). It therefore, suggests that the zooplankton biomass along the east coast is not wholly supported by the availability of phytoplankton biomass, but these organisms sustain on alternate sources of energy during all the seasons and more so during the monsoon season.

5.6 Discussion

The biological productivity in coastal waters of the Arabian Sea (AS) and the Bay of Bengal (BoB) are largely influenced by the physical forcing that these basins are being subjected to, but in contrasting way. The BoB receives large volumes of freshwater due to the opening of several large rivers during the summer, reducing the surface salinity which creates a highly stable barrier layer or stratification and prevents vertical mixing and supply of nutrients from deeper waters (Lucas and Lindstorm, 1991; Sprintall and Tomczak, 1992; Prasannakumar, et. al., 2002). The excess of precipitation over evaporation is another source of freshwater in the BoB (Prasad, 1997). The barrier persists althrough the late summer and the entire post-monsoon season which has a profound impact on the biological productivity of the BoB (Muraleedharan, et. al., 2007). The winds prevailing over BoB is not strong enough to break the barrier. Also the upwelling in the BoB is confined nearer to the coast and only along the southern boundary during the summer (Murty and Varadachari, 1968; Shetye, et. al., 1991; Rao, 2002; Muraleedharan, et. al., 2007).

The BoB is generally considered to be low in biological productivity compared to the Arabian Sea. This is mainly due to the fact that the nutrients brought in by the rivers are being removed in the deeper layers because of the narrow shelf of the bay (Qasim, 1977; Sengupta, et. al., 1977).

The Arabian Sea (AS), on the other hand, experiences strong coastal upwelling during the summer monsoon (Ramamirtham and Jayaram, 1960; Banse, 1968; Madhupratap, et. al., 1990), enriching the upper water column and thereby enhancing the biological productivity. Nutrient rich upwelling waters from the Somalia and Arabia coasts are also being transported to the central Arabian Sea, further giving an impetus to the biological productivity (Prasannakumar, et. al., 2001). In the AS, in contrast with the BoB, the evaporation exceeds precipitation and runoff (except off the west coast of India) (Venkateshwaran, 1956) and this results in the high surface salinities. With the winter cooling experiencing in the north, it leads to formation of high saline water masses that sink and replenishes the upper sub-surface layers (Prasannakumar and Prasad, 1999; Dietrich, 1973). Further the shallow and wide shelf facilitates mixing and enrichment of nutrients, keeping the biological productivity of the coastal waters, generally high throughout the year.

Qasim, (1979), Bhattathiri, et. al., (1980) and Devassy, et. al., (1983) have reported that chl *a* concentrations vary widely without showing any geographic or seasonal patterns.

Radhakrishna, et. al., (1978) have reported that surface chl *a* to ranges from 0.084 to 1.67 mg m^{-3} and that of euphotic column varies from 8.63 to 28.45 mg m^{-2} during 1976 summer monsoon in the Bay of Bengal. For the 1978 summer monsoon, the column chl *a* in the euphotic zone ranged from 1.28–33.72 mg m^{-2} in the offshore waters (Bhattathiri, et. al., 1980) and from 0.01 to 1.01 mg m^{-3} in the surface waters. Concentrations were in the range of 2.11–23.60 mg m^{-2} during 1977 monsoon months and the surface concentrations varied from as low as 0.03 to a high of 1.04 mg m^{-3} in the Bay of Bengal. (Devassy, et. al., 1983). observed surface chl *a* in the range of 0.06–0.28 mg m^{-3} in the Bay of Bengal.. The surface chlorophyll *a* in the central Bay of Bengal increased weakly from 0.06 mg m^{-3} in the south to 0.28 mg.m^{-3} in the north. In the Arabian Sea, the variation was from 0.32 to 1.12 mg m^{-3} indicating that it was 4–5 times higher compared to the Bay of Bengal (Prasanna Kumar, et. al., 2001). In this present study, the overall range along the west coast ranged from 0.04 to 5.24 $mgCm^{-3}$ during monsoon season. Along the east coast it ranged from 0.04 to 0.67 $mgCm^{-3}$ during monsoon season. Along the Goa coast, chlorophyll ranged from 0.05 $mgCm^{-3}$ during premonsoon to 3.7 $mgCm^{-3}$ during the monsoon while at the Mangalore coast it ranged from 0.04 to 5.24 $mgCm^{-3}$ both during monsoon season. Seasonal and annual variations in chlorophyll observed was due to the prevailing physical and chemical conditions. But the low chlorophyll recorded in the BOB in the present study corroborate the earlier reports and can be attributed to the physical forcing to which BOB is subjected to. The sub-surface chlorophyll maxima was observed during all the seasons at the west coast stations. However, the same was not observed at the east coast stations and the maxima was at near-surface depth. This could be the results of stratification which prevents vertical mixing. In CCA performed also indicated high chlorophyll values along the west coast stations.

Zooplankton biomass varied from the lowest of 0.4 ml m^{-3} (monsoon and post-monsoon) to the highest of 7.1 ml m^{3} (monsoon season) along the west coast. The same along the east coast was 0.17 ml m^{-3} (premonsoon) and 5.5 ml m^{-3} (monsoon). Along both the coasts, the highest biomass was observed during the summer monsoon season when the coastal waters are rich in nutrients and phytoplankton.

High zooplankton standing stock and abundance were observed during early monsoon and post-monsoon periods along the southwest coast of India (Madhupratap, et. al., 1992). Pillai & Nair, (1973) observed seasonal fluctuation in the planktonic organisms in the southwest coast of India and reported that southwest monsoon period was the least productive for zooplankton. Two peaks of zooplankton production one during the monsoon and other during pre-monsoon were observed by Suresh & Reddy, (1975) along the Mangalore coast. Further they have reported an increase in quantity of both phytoplankton and zooplankton at the end of monsoon. Nair, (1978), observed two peaks one during post-monsoon and another during pre-monsoon periods at Karwar while two peaks of zooplankton standing stock were observed by Tiwari & Nair, (1993), one during August and other during September (monsoon) at Dharmatar creek. Goswami & Padmavati, (1996), observed bimodal zooplankton production in the coastal waters of Goa, one during late monsoons and other during pre-monsoon. Ramamurthy & Ganapathi, (1975) observed major and minor peaks of zooplankton abundance coinciding with the southwest and northeast monsoon period, respectively at the Vishakapatnam coast.. They attributed the occurrence and abundance to seasons, depth of sampling and hydrographic conditions. Peak of zooplankton production during the post-monsoon following the high phytoplankton production was observed by Nair & Ramaiah, (1998) in coastal waters of Bombay. They also have reported that omnivores dominate the zooplankton community among copepod group. Peaks of zooplankton production one during July –September period and other during November have been noticed by Menon & George, (1977) along the southwest coast of India. They also have recorded spatial and temporal variations in the quantitative abundance of zooplankton in coastal waters of Mangalore. All the earlier studies have also recorded higher zooplankton standing stock during the monsoon period as observed in the present study. However, the biomass recorded along the Kakinada coast was lower and could be attributed to low phytoplankton. George & Nair, (1980) observed higher biomass values between Mangalore and Alleppy and Santhakumari, (1991) observed higher biomass during the post-monsoon in relation with low water temperature and dissolved oxygen. Padmavati & Goswami, (1996a), found species richness and evenness to be inversely related to zooplankton biomass. Santhakumari & Saraswathy, (1981), observed high biomass of zooplankton, mainly contributed by ostracods, salpids, chaetognaths and decapods. Dominance of filter feeders followed by omnivores and predators in the zooplankton community was observed by Nair, (1980) in the Goa coast.

Pati, (1980) observed three phytoplankton blooms followed by zooplankton maxima during the spring and fall seasons along the Balasore (Orissa) coast. During the upwelling period Achuthankutty, et. al., (1998) observed that highest zooplankton production in the coastal waters of Goa.

Qasim, et. al., (1978), studied the biological productivity of coastal waters of India and found that copepods formed the dominant group among 18 other major components of zooplankton. Subbaraju & Krishnamurthy, (1972), observed that copepod comprised 80-95% of zooplankton population and related the fluctuations in annual cycle of plankton to the changes in seasonality of salinity and rainfall in the Bay of Bengal. Rakesh, et. al., (2006) found copepods to be the dominant group in zooplankton community. They also observed high zooplankton diversity in the open sea locations as compared to the coastal waters. Dominance of copepods in the zooplankton community was also observed at all the stations during all the seasons along both the coasts during the present study (>60%). This was obviously due to the herbivorous feeding behaviour of copepods.

Herbivores formed a sizeable part of the zooplankton community. Different types of trophic relationships between the phytoplankton and zooplankton have been established in estuarine systems (Sautour, et. al., 1996; Perissinotto, et. al., 2000; Tan, et. al., 2004). It has been traditionally thought that the major contributions to primary production in coastal and estuarine waters came from diatoms, which subsequently get transferred to fish through copepods. However, recent studies on size-fractionated plankton communities have questioned this view, often implicating the importance of microzooplankton as the major consumers of phytoplankton in the coastal waters (Gifford, 1988; Leising, et. al., 2005; Madhupratap, et. al., 1996, 2001; Gauns, et. al., 2005). Herbivorous mesozooplankton feed on very small particles including bacteria (Sherr & Sherr, 1987; Sorokin, Yu. I, 1981). In the present study, it was found that the energy available at the primary level in the Bay of Bengal was lower than that in the Arabian Sea. Heterotrophic and mixotrophic models were well represented in the marine plankton including mesozooplankton and are known to consume a variety of food items like detrital material including carcasses and faeces (Hansen, et. al., 1991; Lessard, 1991). In the Arabian Sea, microzooplankton and mesozooplankton are major players in conversion and re-mineralization (Sarma, et. al., 2003). Copepods are known to graze 50 – 100% of diatom population though the impact of microzooplankton is equally important (Landry, et. al., 1998; Smith, 2001) Studies of Berggreen, et. al., (1988); Ohman & Runge, (1994) have shown that herbivorous zooplankton also consume other available particles apart from consuming phytoplankton, indicating a switchover in feeding behaviour. Gauns et al. (2005) encountered the ratios of autotrophic to heterotrophic biomass to be quite low (during April – may) about 0.1, monsoon season 0.7 was encountered while during the post-monsoon 0.3, which suggests heteretrophic conditions in the Arabian Sea. In the present study heterotrophy was found to be more pronounced along both the coast, suggesting that mesozooplankton does not depend only on phytoplankton for food. However, only during the southwest monsoon autotrophy was observed along the west coast. This was due to the high population of phytoplankton biomass sustaining during the season. The nutrient enrichment in the upper water column due to coastal upwelling and land runoff, facilitates enhanced primary productivity and this is quite sufficient to support the energy requirement of the mesozooplankton as observed presently. Along the east coast a very contrasting picture was observed. During the monsoon season, the herbivory was strongly prevailing compared to other two seasons. This could be due to high mesozooplankton population present during this season which could not be supported by the phytoplankton population. This clearly points to the fact that the upwelling along the west coast supports the formation of a high phytoplankton population which can provide the energy requirement of the large population of zooplankton. On the contrary, the strong stratification coupled with weak upwelling along the west coast limit nutrient enrichment to the upper surface water column, thereby reducing phytoplankton growth and resulting in low zooplankton standing stock.

Table 5.1: Distribution of mesozooplankton taxal groups (ind.m-3) along theGoa transect during pre-monsoon

Groups	Stn. 1	Stn. 2	Stn. 3
Siphonophore	512	13	25
Medusae	50	0	6
Polychaete	1295	25	0
Copepods	13879	8477	4781
Cladocerans	1019	25	0
Ostracods	11917	1512	66
Amphipods	0	1	3
Euphasiids	0	6	28
Lucifer	181	100	22
Crustacean nauplii	0	25	0
Penaeids	2	0	0
Brachyurian zoea	0	31	19
Other decapods	0	44	20
Stomatopods	0	0.4	0
Chaetognaths	412	270	323
Bivalve larvae	412	402	28
Gastropod larvae	412	1129	82
Pteropods	141	351	154
Oikopleura	637	63	267
Salps	0	0	0.2
Doliolum	90	0	3
Fish larvae	27	31	3
Invertebrate eggs	0	0	0
Foram	0	358	44
Echinoptitus	0	6	9
Total density	**30986**	**12869.4**	**5883.2**

Table 5.2: Distribution of mesozooplankton taxal groups (ind.m-3) along theGoa transect during monsoon

Groups	Stn.1	Stn.2	Stn.3
Siphonophore	57	124	19
Medusae	1337	6	51
Ctenophore	111	0	0
Polychaete	5677	2158	33
Copepods	106685	22279	2625
Cladocerans	24543	3147	14
Ostracods	4	118	107
Cirripede larvae	501	0	0
Amphipods	14	0	33
Euphasiids	0	0	84
Lucifer	1574	285	0
Brachyurian zoea	447	0	0.9
Other decapods	0	0.4	0
Chaetognaths	612	118	102
Bivalve larvae	445	46	0
Gastropod larvae	0	34	19
Pteropods	501	34	0
Oikopleura	6400	4638	218
Salps	2671	1255	0
Doliolum	668	229	33
Fish eggs	0	334	0.1
Fish larvae	501	34	19
Total density	**152748**	**34839.4**	**3358**

Table 5.3: Distribution of mesozooplankton taxal groups (ind.m-3) along theGoa transect during post-monsoon

Groups	Stn.1	Stn.2	Stn.3
Siphonophore	111	299	79
Medusae	148	19	26
Ctenophore	0	8	0
Polychaete	93	11	9
Copepods	8125	7523	2495
Cladocerans	0	132	0
Ostracods	186	379	246
Amphipods	3395	0	33
Mysids	1	0	1
Euphasiids	5	17	19
Lucifer	100	0	3
Penaeids	2	0	0
Brachyurian zoea	79	4	7
Megalopa	151	0	0
Other decapods	14	14	6
Stomatopods	9	8	0
Chaetognaths	223	44	227
Bivalve larvae	19	6	19
Gastropod larvae	93	13	26
Pteropods	93	19	19
Oikopleura	148	50	489
Salps	39	0	2
Doliolum	79	53	9
Fish larvae	79	0	2
Phoronid	0	8	0
Bryozoa	0	23	0
Total density	13192	8630	3717

Table 5.4: Distribution of mesozooplankton taxal groups (ind.m-3) along the Mangalore transect during pre-monsoon

Groups	Stn 4	Stn 5	Stn 6
Siphonophore	59	167	203
Medusae	0	25	8
Ctenophore	0	13	0
Polychaete	42	42	62
Copepods	7764	5681	5848
Cladocerans	335	0	5
Ostracods	34	3150	510
Amphipods	0	67	17
Mysids	0	17	30
Euphasiids	0	163	77
Lucifer	84	42	1
Penaeids	0	13	0
Brachyurian zoea	17	109	1
Megalopa	17	2	0.3
Other decapods	1	1385	77
Stomatopods	17	1	0
Chaetognaths	284	514	460
Bivalve larvae	0	17	0
Gastropod larvae	17	38	66
Pteropods	17	67	26
Oikopleura	912	402	499
Salps	0	540	114
Doliolum	117	54	54
Fish eggs	42	0	19
Fish larvae	0	42	8
Invertebrate eggs	0	0	2
Foram	17	0	19
Bryozoan I	0	1	0
Echinoderm I	0	1	0
Total density	**9776**	**12553**	**8106.3**

Table 5.5: Distribution of mesozooplankton taxal groups (ind.m-3) along the Mangalore transect during monsoon

Groups	Stn.4	Stn.5	Stn.6
Siphonophore	376	0.6	10
Medusae	0	74	0
Ctenophore	187	0	0
Polychaete	1056	519	37
Copepods	71634	28086	11056
Cladocerans	3054	1	0
Ostracods	542	111	56
Cirripede larvae	0	0	0
Amphipods	0	37	1
Cumaceans	0	0.6	0
Euphasiids	4	189	38
Lucifer	378	5	0.6
Penaeids	0	0.6	0
Brachyurian zoea	0	0	0.6
Megalopa	0	0.6	0.3
Other decapods	0	0	7
Stomatopods	0	5	0.6
Chaetognaths	1085	890	186
Bivalve larvae	371	0	19
Gastropod larvae	457	0	0
Pteropods	0	2	0
Oikopleura	13728	9609	2541
Salps	21	0	0
Doliolum	371	0	14
Fish eggs	0	0	19
Fish larvae	375	5	42
Invertebrate eggs	5822	0	93
Foram	86	37	0
Bryozoa	0	0	1
Total density	**99547**	**39572.4**	**14122.1**

Table 5.6: Distribution of mesozooplankton taxal groups (ind.m-3) along the Mangalore transect during post-monsoon

Groups	Stn.4	Stn.5	Stn.6
Siphonophore	134	2	56
Medusae	45	0.7	21
Ctenophore	45	0	0
Polychaete	45	121	4
Copepods	3562	5086	5565
Ostracods	89	231	186
Cirripede larvae	0	24	0
Amphipods	45	0	74
Isopods	0	0	0.6
Mysids	0.7	0	0.6
Euphasiids	0.7	23	75
Acetes	0	3	0
Lucifer	134	9	0.6
Penaeids	0	0.4	0.6
Brachyurian zoea	45	0.7	56
Megalopa	0	21	0
Other decapods	91	0	93
Stomatopods	2	6	0
Chaetognaths	89	49	334
Bivalve larvae	134	4	0
Gastropod larvae	45	20	93
Pteropods	223	2	93
Oikopleura	312	18	519
Salps	0	0	19
Doliolum	45	0.7	3
Fish eggs	2	0	0
Fish larvae	1	0	0
Invertebrate eggs	0	7	0
Pontellid larvae	0	3	0
Bryozoa	0	0.2	0
Total density	**5089.4**	**5631.7**	**7193.4**

Table 5.7: Distribution of mesozooplankton taxal groups (ind.m-3) along the kakinada transect during pre-monsoon season

Groups	Stn.1	Stn.2	Stn.3	Stn.4	Stn.5	Stn.6
Siphonophores	27.9	0.2	7.2	0	0.4	14.3
Medusae	0.4	14.3	0	0	71.7	14.3
Ctenophores	0	0	7.2	4.6	0	0
Polychaetes	0.2	0.1	0.2	0	0.3	0.1
Copepods	390.4	437.4	258.2	301.2	258.2	121.9
Cladocerans	0	0	0	0	0	0
Ostracods	0.9	0.2	0.1	0.8	0.1	0.4
Amphipods	0	0.2	0.2	0	0.3	0.2
Euphausiids	0	0.2	0.3	0	0.1	0
Lucifer	2.2	0.4	0.2	0	0	0.3
Penaeids	0	0.1	0	0	0	0
Brachyurian Zoeae	0.4	0.1	0	0	0.2	0.3
Megalopa stage	0	0	0	0	0	0
Other decapods	1.1	0.7	0.7	2.1	0.2	1
Porcellanid Zoeae	0	0	0	0	0	0
Stomatopods	0.4	0.1	0.1	0.4	0	0
Chaetognaths	111.5	14.3	7.2	1.3	28.7	7.2
Bivalve larvae	27.9	0	0	0	0.7	0
Gastropod larvae	0	7.2	7.2	33.5	0	0
Pteropods	0	0.1	0.1	0.5	0.4	7.2
Oikopleura	0	28.7	21.5	66.9	7.2	28.7
Salps	0	0.2	0.2	0.8	14.3	0.6
Doliolids	0.4	0.1	0.1	1	0	0.2
Fish eggs	0.2	14.3	0.3	0.4	28.7	0.2
Fish larvae	0.4	0.1	0	0.5	0.1	0.2
Total density	**564.3**	**519**	**311**	**414**	**411.6**	**197.1**

Table 5.8. Distribution of mesozooplankton taxal groups (ind.m-3) along the kakinada transect during monsoon season

Groups	Stn.1	Stn.2	Stn.3	Stn.4	Stn.5	Stn.6
Siphonophores	31.4	50.2	82.6	80	89	45.6
Medusae	56.5	25.1	11.8	0	6.9	18.2
Ctenophores	0	0	0	0	0.2	9.1
Polychaetes	12.5	75.3	11.8	40	89	27.3
Copepods	14054.9	4392.2	7219.9	38400	6767.3	5976.4
Cladocerans	0	0	0	2.5	0	9.1
Ostracods	21.9	175.7	35.4	360	133.6	100.2
Amphipods	87.8	1.6	0.7	40	22.3	18.2
Mysids	0	0	2.2	0	0	0
Euphausiids	0	0	1.5	0	1.4	54.7
Cirripede larvae	0	0	0	0.6	0	0
Acetes	0	1.6	35.4	360.3	22.4	9.1
Lucifer	9.4	76.9	4.9	285.5	47.3	56.4
Penaeids	9.4	0	11.8	200	6.9	27.3
Brachyurian Zoeae	6.3	3.1	0.4	40	1.4	18.2
Megalopa stage	0	0	0.4	2.5	1.4	0
Other decapods	0.2	3.2	1.3	6.1	12.3	5.9
Porcellanid Zoeae	0	0	0	0	0.2	0
Stomatopods	3.1	1.9	0.4	3.8	0.2	9.1
Chaetognaths	241.6	1756.9	176.9	1360	356.2	182.2
Bivalve larvae	175.7	50.2	11.8	1280	445.7	2.3
Gastropod larvae	6.3	25.1	3.7	480	2.8	9.1
Pteropods	34.5	125.5	23.6	440	22.3	27.3
Oikopleura	18.8	125.5	58.9	760	22.3	264.2
Salps	1.6	3.1	0.4	40	2.8	9.1
Doliolids	0	4.7	1.5	40	0	18.2
Fish eggs	15.7	0	1.1	5	22.3	1.1
Fish larvae	3.1	7.8	0.7	2.5	1.4	1.1
Bryozoan larvae	3.1	0	0	0	0	0
Echinoderm larvae	0	0	0	0	0	9.1
Total density	**14793.8**	**6905.6**	**7699.1**	**44228.8**	**8077.6**	**6908.6**

Table 5.9: Distribution of mesozooplankton taxal groups (ind.m-3) along the kakinada transect during post-monsoon season

Groups	Stn. 1	Stn.2	Stn.3	Stn.4	Stn.5	Stn.6
Siphonophore	29.86	10.31	18.603	4.25	10.51	9.1
Medusae	14.54	4.04	6.47	0.57	7.48	6.07
Ctenophore	0	0	0	0	0.61	0
Polychaeta	14.54	2.43	11.73	5.38	12.94	6.67
Copepod	1807.47	1273.89	3194.82	892.29	2517.44	980.69
Cladocera	0	0	0	0	0.81	0
Ostracod	0.39	0.61	0	0	0.4	0.2
Amphipod	0.79	0.4	3.64	1.13	1.01	0.62
Mysid	0	2.22	0	0	0	2.22
Euphausids	0	0	3.24	0	1.82	0.2
Lucifer	3.54	11.93	0.4	1.13	1.82	11.53
Decapod	0.39	4.85	4.45	0.28	3.44	1.42
Stomatopods	0	0.2	0.4	0	0	0
Chaetognatha	113.95	52.78	82.5	20.1	96.25	47.72
Gastropod	0.39	0	0	0	0.4	0.2
Heteropod	0.39	0.61	0	0.28	0.4	0.2
Cephalopod	0	0	0	0	0.2	0
Pteropod	1.57	2.43	2.43	0.28	1.82	1.62
Oikopleura	154.81	46.51	100.29	28.31	87.35	116.47
Salps	0	0	0	0.28	0.2	2.02
Doliolids	4.72	6.27	7.28	0.42	5.66	7.28
Fish egg	1.57	0.4	0	0	0	0
Fish larva	0.39	0.61	1.21	0	1.01	0.81
Amphioxus	1.57	0.2	1.21	0	1.82	0.2
Pyrosoma	0	0	0.4	0	0	0
Total density	**2150.88**	**1420.69**	**3439.073**	**954.7**	**2753.39**	**1195.24**

Table 5.10. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Goa & Mangalore during pre-monsoon)

	Group 3	Group 2		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Ostracods	11916.6	772.8	51.96	51.96
Copepods	13879.2	8120.2	26.85	78.8
Polychaete	1295	33.45	5.87	84.67
Cladocerans	1019	179.85	3.88	88.55
Gastropod larvae	411.6	573.06	2.56	91.11

	Group 3	Group 1		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Ostracods	11916.6	1242	44.53	44.53
Copepods	13879.2	5436.5	35.02	79.55
Polychaete	1295	34.6	5.22	84.77
Cladocerans	1019	1.63	4.21	88.98
Other decapods	0	493.63	1.88	90.85

	Group 2	Group 1		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Groups	8120.2	5436.5	39.93	39.93
Ostracods	772.8	1242	17.34	57.27
Gastropod larvae	573.06	61.8	7.63	64.91
Oikopleura	487.3	388.87	6.41	71.32
Other decapods	22.45	493.63	5.97	77.28
Cladocerans	179.85	1.63	2.82	80.1
Salps	0	217.8	2.77	82.87
Bivalve larvae	200.8	14.97	2.75	85.62
Foraminifera	187.2	20.9	2.4	88.03
Pteropods	184.05	82.3	2.37	90.39

Table 5.11. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Goa & Mangalore during monsoon)

	Group 2	Group 1		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	89159.8	25182.6	69.27	69.27
Cladocerans	13798.15	1574.3	11.9	81.17
Oikopleura	10063.75	7123.45	5.55	86.72
Invertebrate eggs	2911.05	0	3.83	90.55

	Group 2	Group 4		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	89159.8	2624.9	70.46	70.46
Cladocerans	13798.15	13.9	9.84	80.3
Oikopleura	10063.75	218	9	89.3
Invertebrate eggs	2911.05	0	2.98	92.28

	Group 1	Group 4		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	25182.6	2624.9	65.89	65.89
Oikopleura	7123.45	218	19.9	85.79
Cladocerans	1574.3	13.9	4.9	90.69

	Group 2	Group 3		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	89159.8	11056.3	69.74	69.74
Cladocerans	13798.15	0	10.97	80.71
Oikopleura	10063.75	2541.4	7.66	88.37
Invertebrate eggs	2911.05	92.8	3.21	91.58

	Group 1	Group 3		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	25182.6	11056.3	59.82	59.82
Oikopleura	7123.45	2541.4	19.1	78.91
Cladocerans	1574.3	0	7.04	85.96
Polychaete	1338.75	37.1	5.73	91.68

	Group 4	Group 3		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	2624.9	11056.3	74.98	74.98
Oikopleura	218	2541.4	20.66	95.64

Table 5.12. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Goa & Mangalore during post-monsoon)

	Group 2	Group 1		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Amphipods	3394.8	24.73	48.32	48.32
Copepods	8125.2	6058.1	30.48	78.79
Oikopleura	148.4	195.86	2.87	81.66
Chaetognaths	222.6	142.4	2.21	83.88
Megalopa	150.7	7.02	2.05	85.93
Medusae	148.4	13.47	1.94	87.87
Siphonophore	111.3	118.76	1.66	89.53
Lucifer	99.7	3.21	1.38	90.91

	Group 2	Group 3		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	8125.2	3028.4	52.12	52.12
Amphipods	3394.8	38.5	34.18	86.3
Oikopleura	148.4	400.5	2.6	88.9
Megalopa	150.7	0	1.53	90.43

	Group 1	Group 3		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	6058.1	3028.4	70.28	70.28
Oikopleura	195.86	400.5	6.85	77.13
Chaetognaths	142.4	158.1	3.18	80.31
Ostracods	265.02	167.4	2.71	83.02
Siphonophore	118.76	106.2	2.65	85.67
Pteropods	37.93	120.6	2.46	88.13
Bivalve larvae	3.49	76.1	1.64	89.77
Lucifer	3.21	68	1.5	91.27

Table 5.13. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Kakinada during pre-monsoon)

	Group 2	Group 1		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	413.92	272.49	45.56	45.56
Chaetognaths	62.94	12.39	17.34	62.9
Oikopleura	14.34	31.87	8.46	71.36
Medusae	7.39	23.9	8.22	79.58
Siphonophores	14.06	2.54	4.36	83.93
Bivalve larvae	13.94	0.22	4.35	88.28
Gastropod larvae	3.59	13.54	3.83	92.11

	Group 2	Group 3		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	413.92	121.9	70.35	70.35
Chaetognaths	62.94	7.17	13.05	83.39
Oikopleura	14.34	28.68	3.34	86.73
Siphonophores	14.06	14.34	3.33	90.06

	Group 1	Group 3		
Zoopl groups	**Av.Abund**	**Av.Abund**	**Contrib%**	**Cum.%**
Copepods	272.49	121.9	57.69	57.69
Medusae	23.9	14.34	10.72	68.41
Oikopleura	31.87	28.68	8.23	76.64
Gastropod larvae	13.54	0	5.06	81.7
Siphonophores	2.54	14.34	4.44	86.14
Fish eggs	9.8	0.22	3.47	89.61
Chaetognaths	12.39	7.17	3.3	92.91

Table 5.14. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Kakinada during monsoon)

	Group 2	Group 1		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	14054.9	6088.95	87.14	87.14
Chaetognaths	241.6	618.05	4.87	92.01

	Group 2	Group 3		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	14054.9	38400	82.05	82.05
Chaetognaths	241.6	1360	3.77	85.82
Bivalve larvae	175.7	1280	3.72	89.54
Oikopleura	18.8	760	2.5	92.04

	Group 1	Group 3		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	6088.95	38400	86.94	86.94
Bivalve larvae	127.5	1280	3.1	90.04

Table 5.15. SIMPER analysis in groups outlined by clusters, showing the organisms which most contributed to the observed differences among groups. (Off Kakinada during post-monsoon)

	Group 1	Group 2		
Zoopl groups	Av.Abund	Av.Abund	Contrib%	Cum.%
Copepods	2506.58	1048.96	89	89
Oikopleura	114.15	63.76	4.06	93.06

Table 5. 16: List of zooplankton group codes

Acetes	Acet
Amphioxus	Amphio
Amphipods	Amphi
Bivalve larvae	Bival
Brachyurian zoea	Brac
Bryozoa	Bryo
Cephalopod	cepha
Chaetognaths	Chaet
Cirripede larvae	Cirrip
Cladoceran	Clado
Copepods	Cope
Crustacean nauplii	Crust naup
Ctenophore	Cteno
Cumacea	Cuma
Doliolum	Dolio
Echinoptitus	Echinop
Euphasiids	Euph
Fish eggs	Fishe
Fish larvae	Fishl
Foraminiferan	Foram
Gastropod larvae	Gastr
Invertebrate eggs	InverE
Isopods	Iso
Lucifer	Lucif
Medusae	Medu
Megalopa	Mega
Mysids	Mysid
Oikopleura	Oiko
Ostracods	Ostra
Other decapods	Deca
Penaeids	Pena
Phoronid	Phoro
Polychaete	Polyc
Porcellanid Zoeae	Porce
Pteropods	Ptera
Pyrosoma	Pyro
Salps	Salps
Siphonophore	Sipho
Stomatopods	Stom

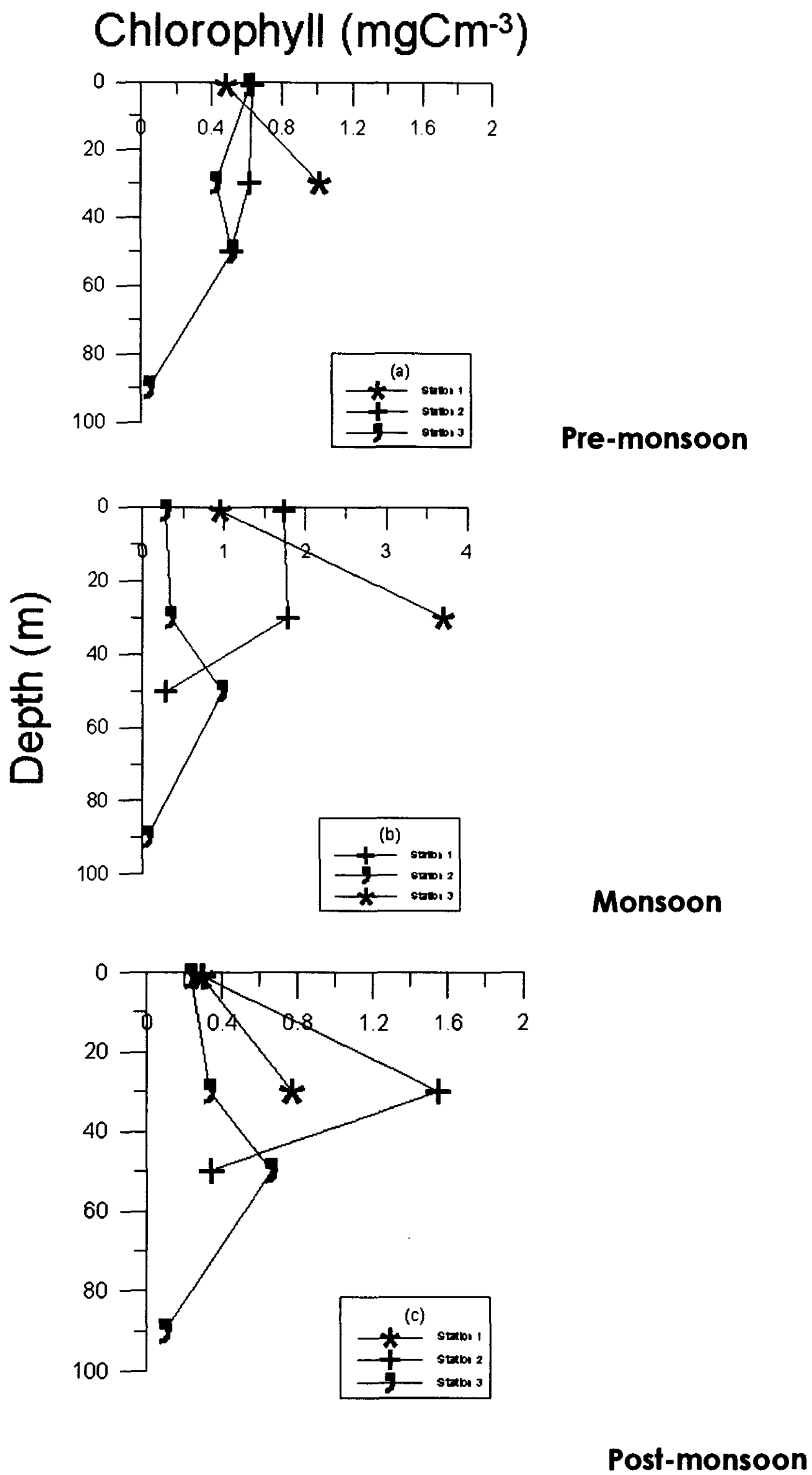


Fig. 5.1. Vertical distribution of Chlorophyll *a* along off Goa transect during different seasons

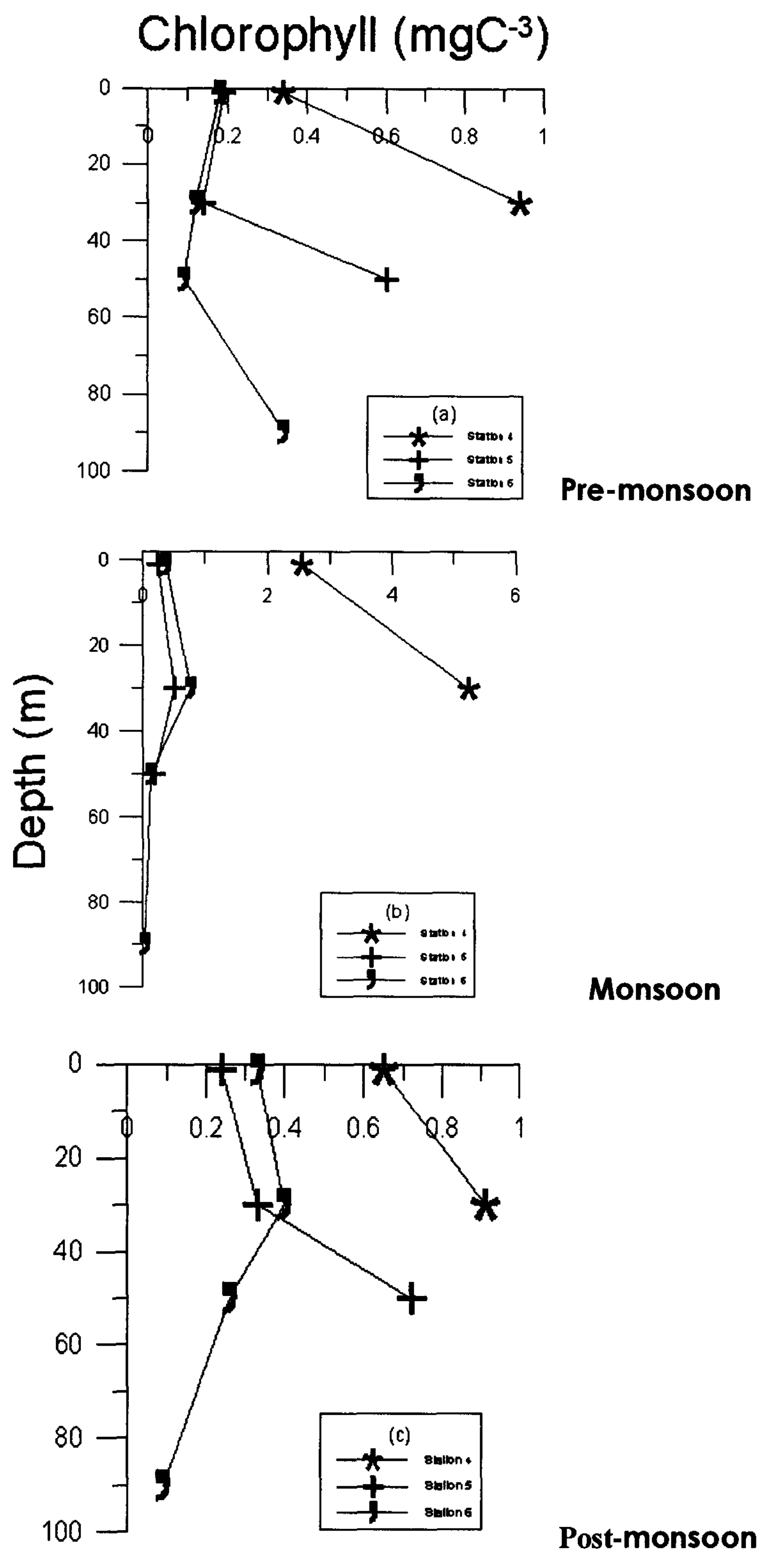
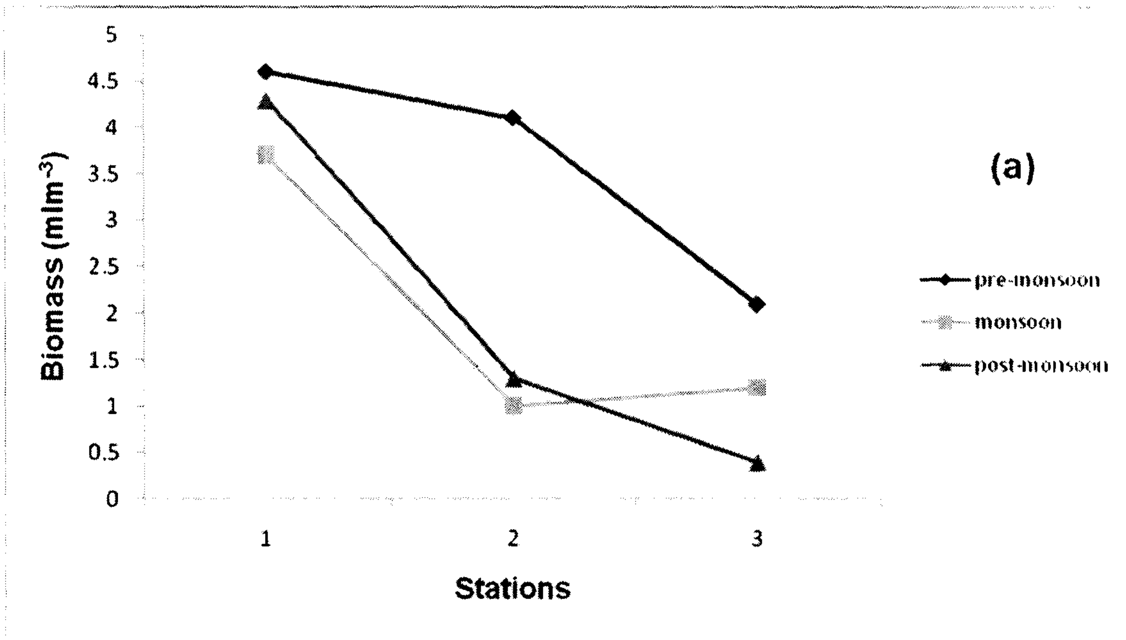


Fig. 5.2. Vertical distribution of Chlorophyll *a* along off Mangalore transect during different seasons



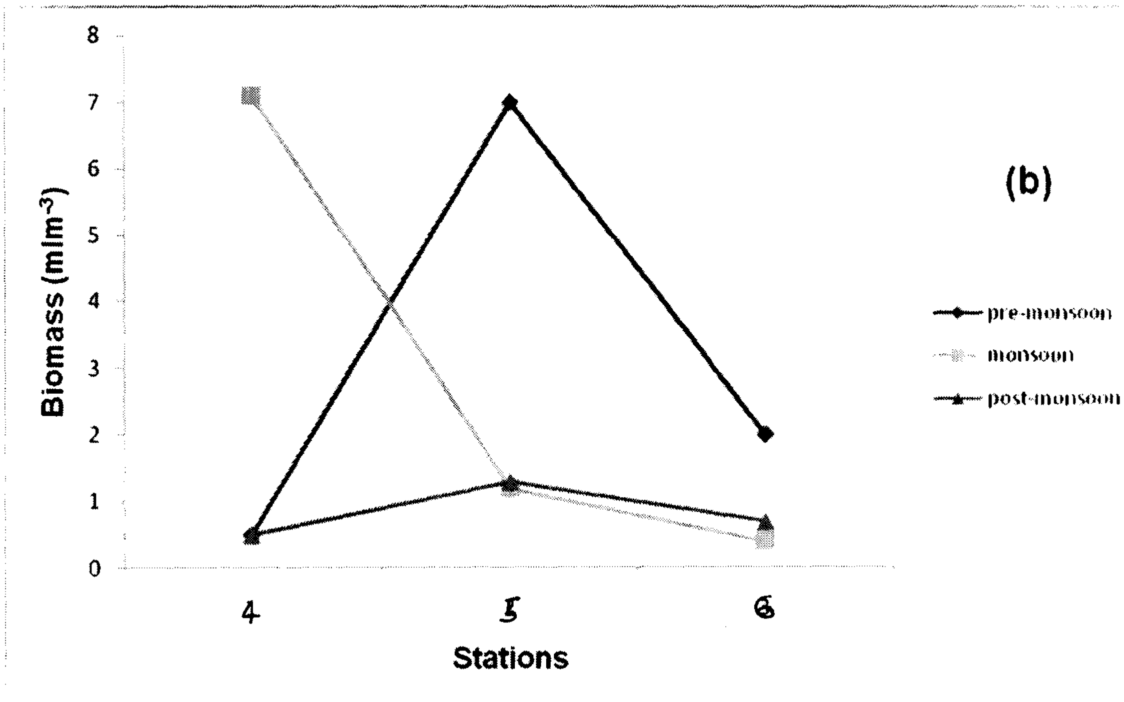


Fig. 5.3. Biomass of mesozooplankton during different seasons along the Goa and Mangalore coasts

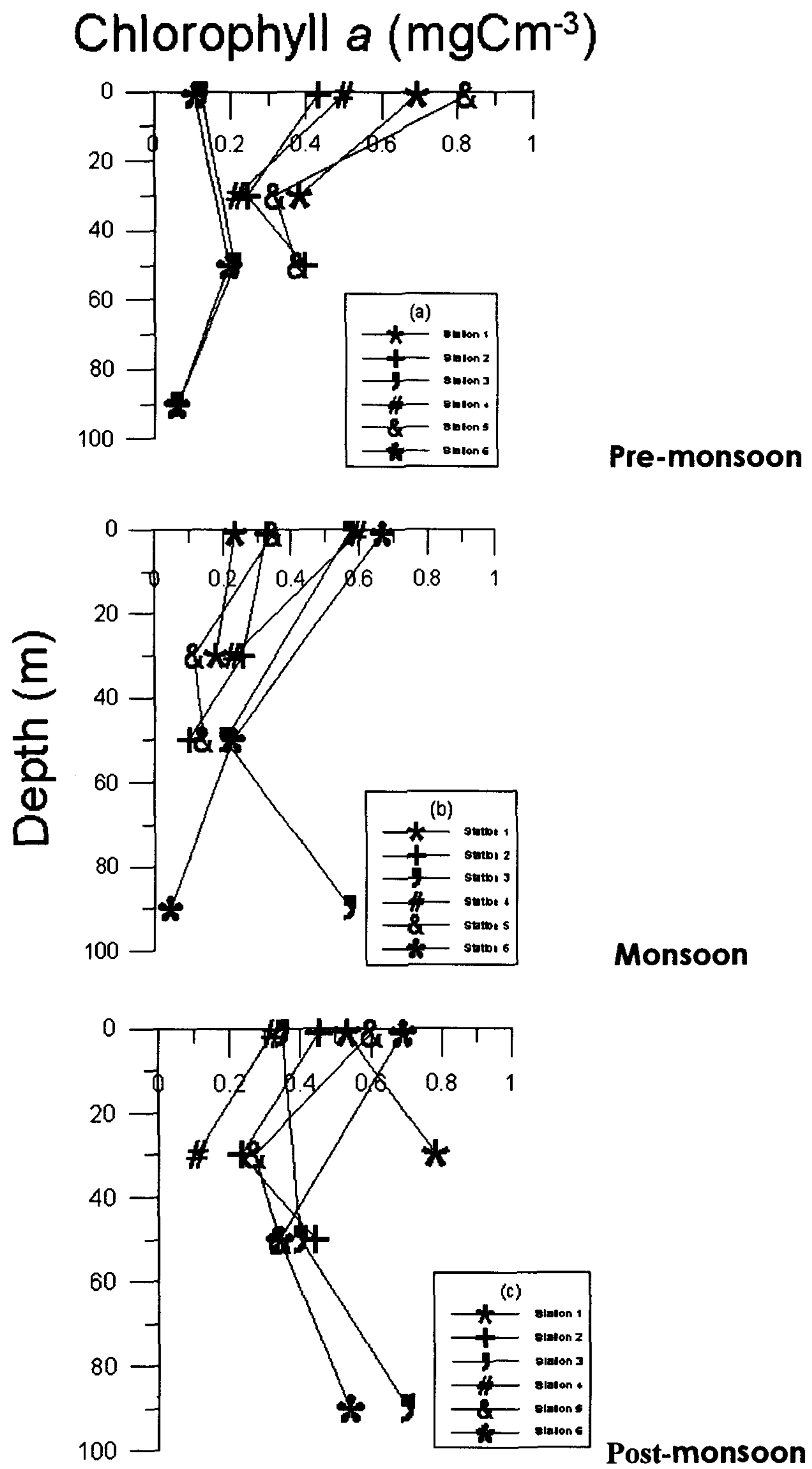


Fig. 5.4. Vertical distribution of Chlorophyll *a* along off Kakinada transect during different seasons

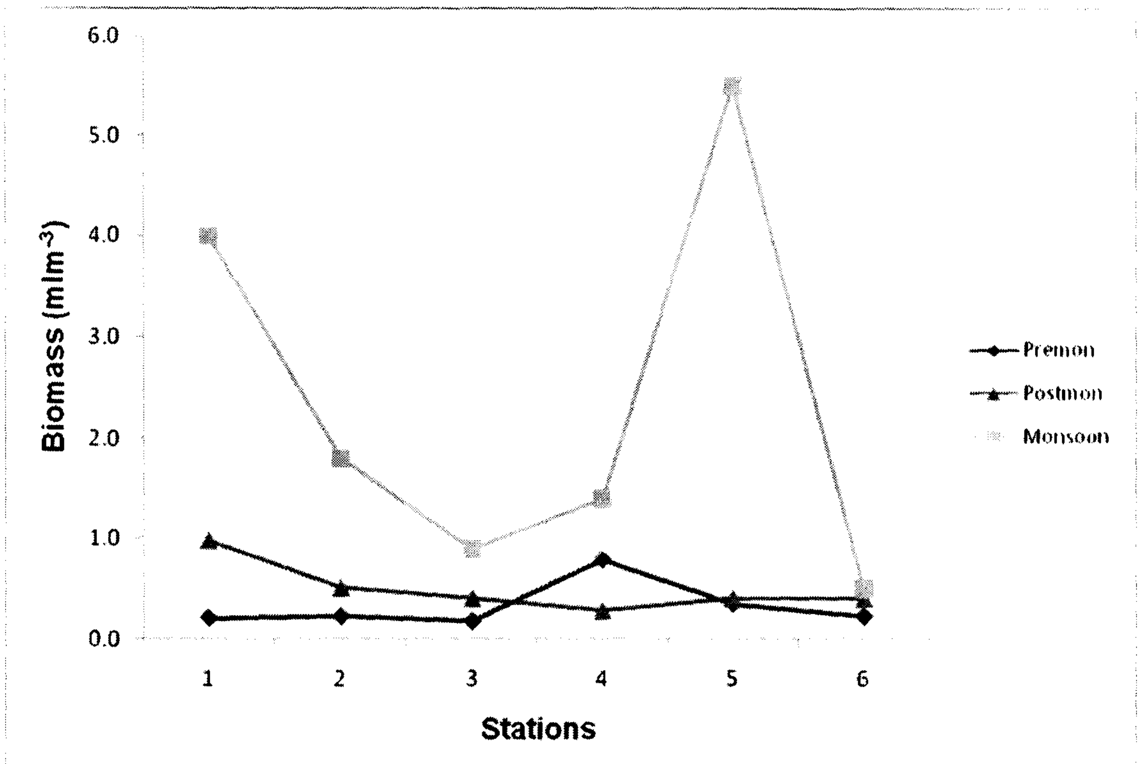
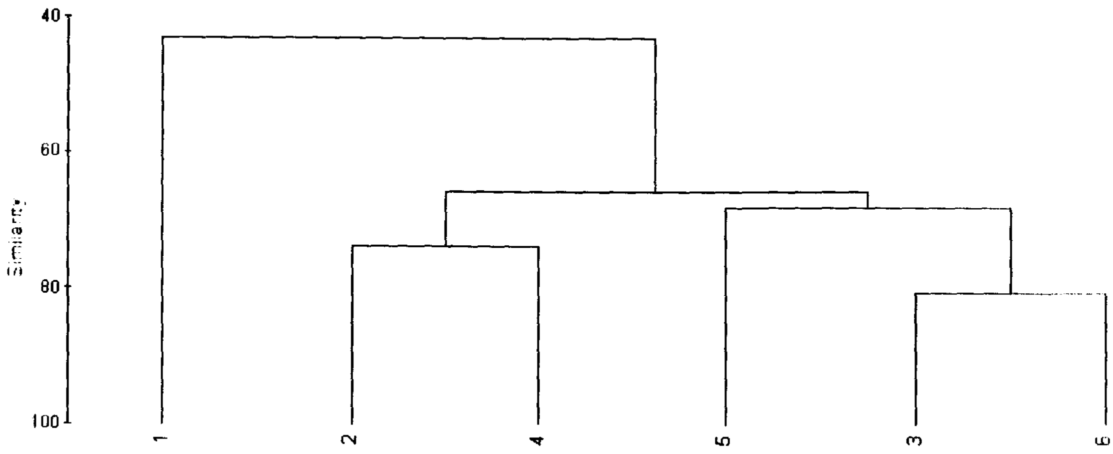


Fig. 5.5. Biomass of mesozooplankton during different seasons along the Kakinada coasts

(a)



(Stations)

(b)

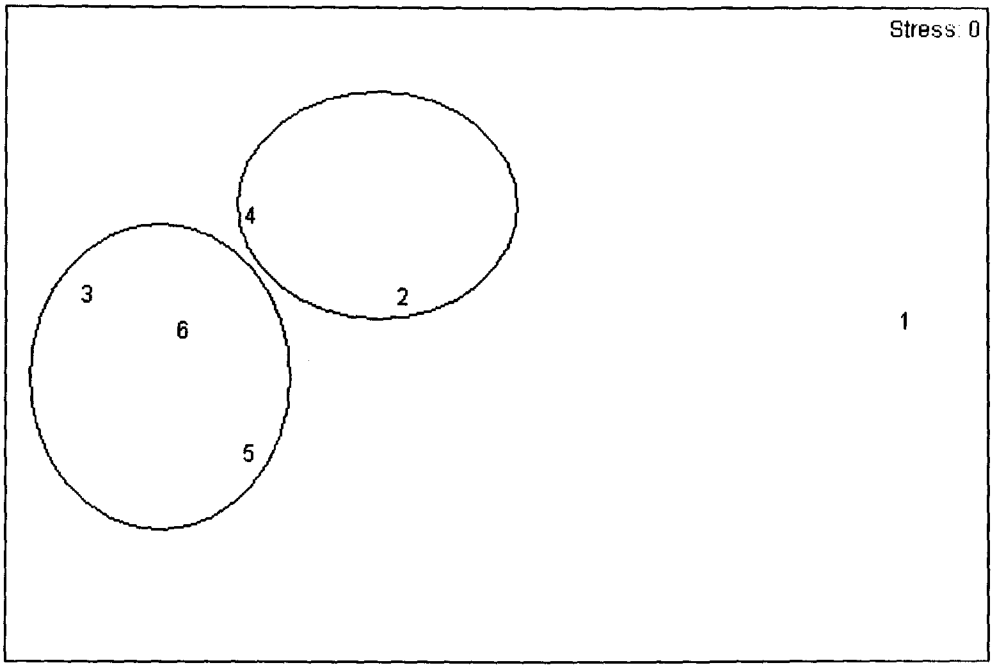
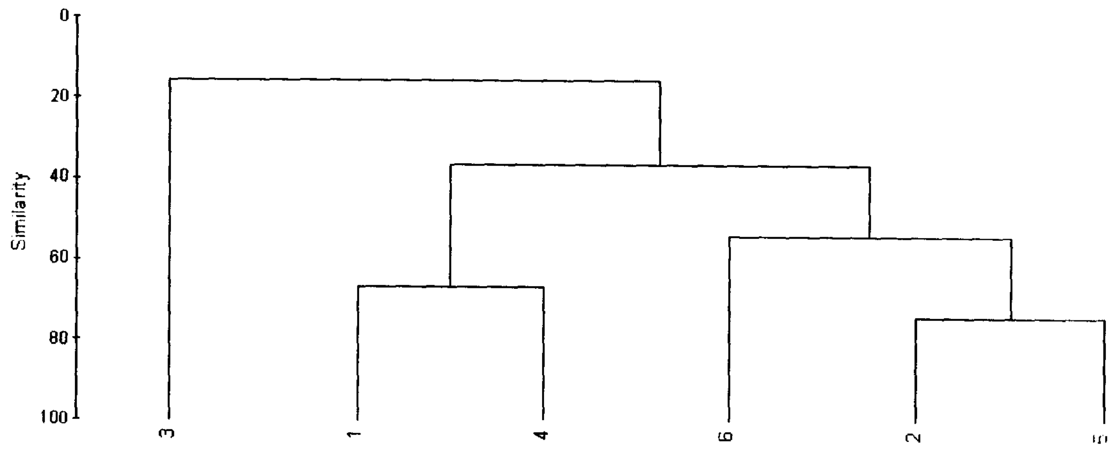


Fig. 5.6. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for west coast during pre-monsoon season

(a)



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(b)

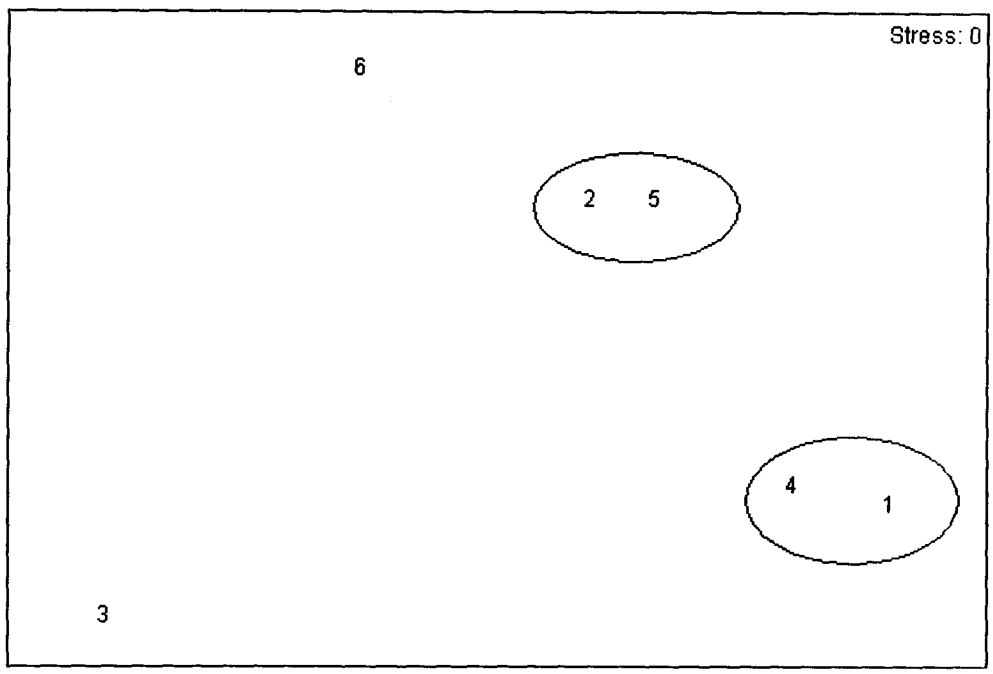
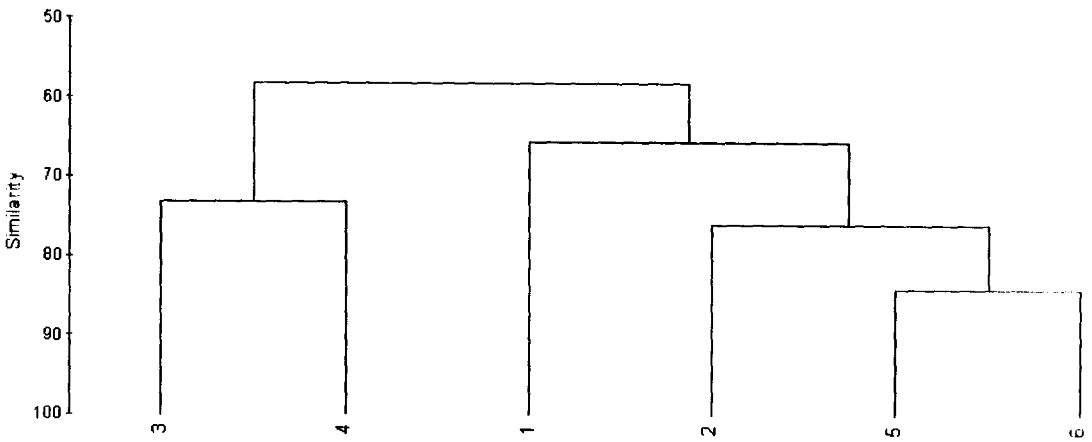


Fig. 5.7. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for west coast during monsoon season

(a)



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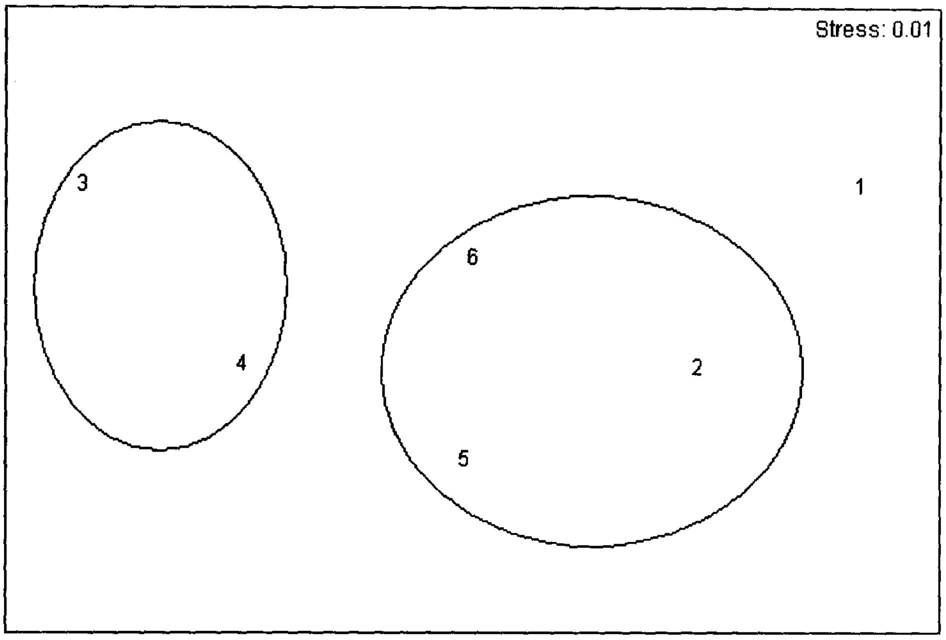
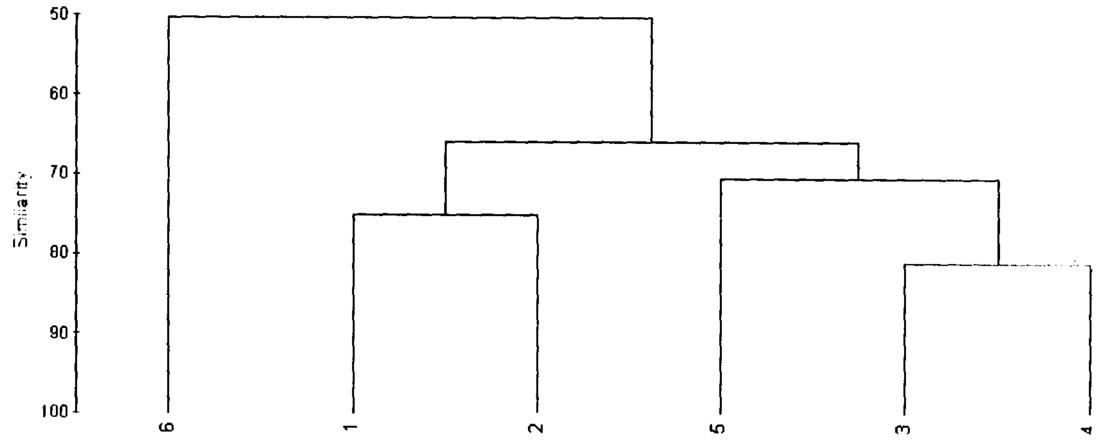


Fig. 5.8. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for west coast during post-monsoon season

(a)



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(b)

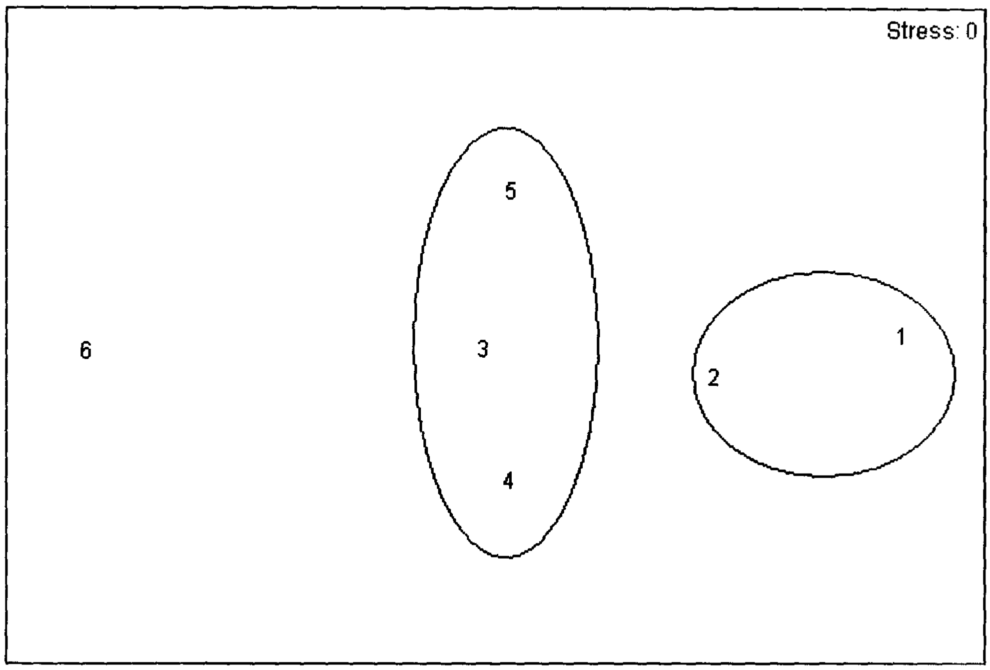
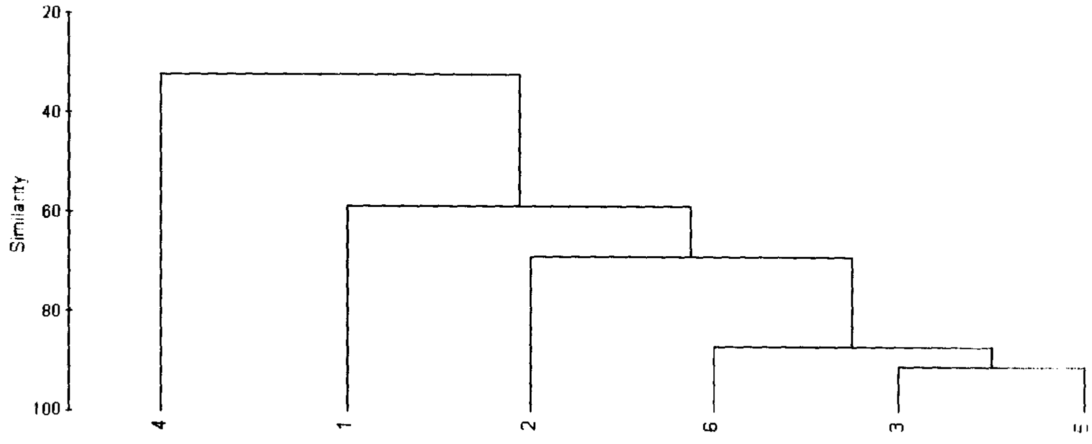


Fig. 5.9. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for east coast during pre-monsoon season

(a)



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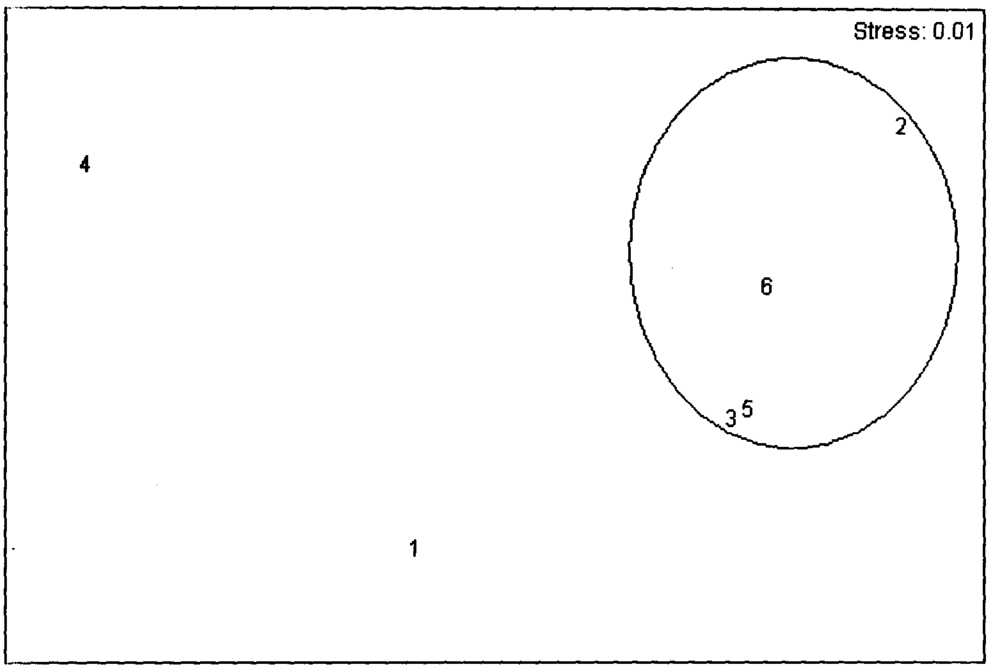
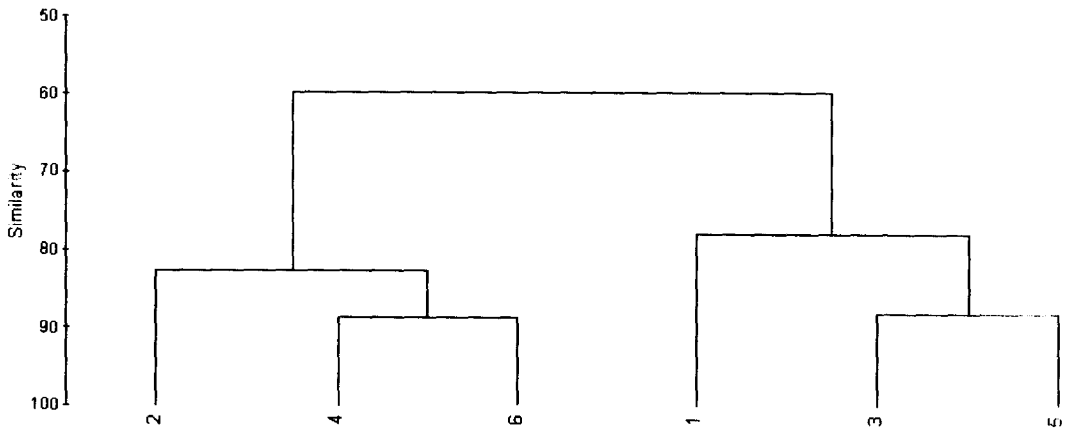


Fig. 5.10. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for east coast during monsoon season

(a)



(Stations)

(b)

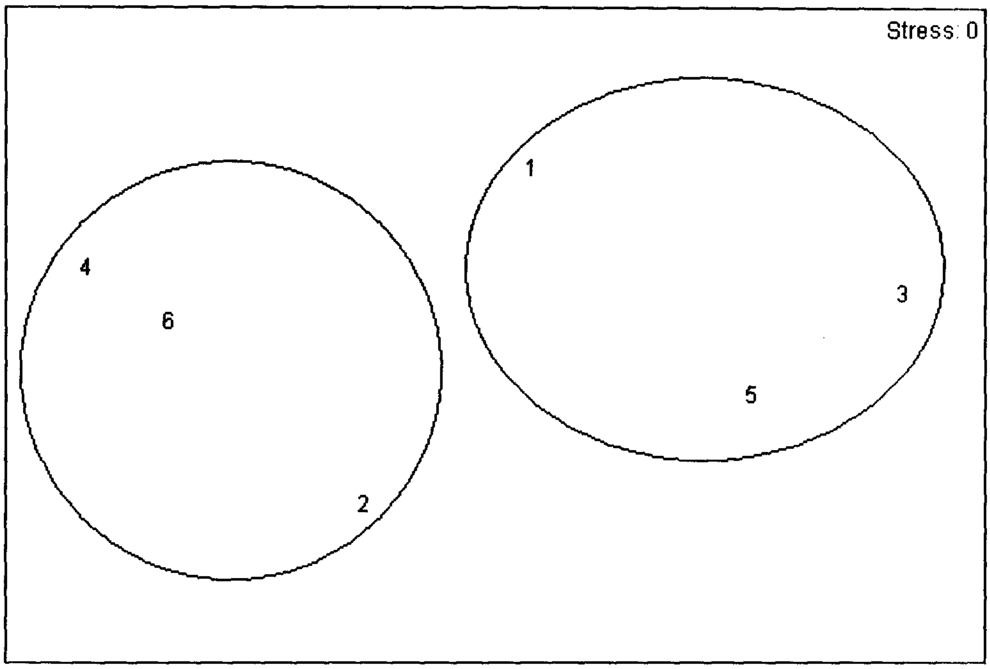
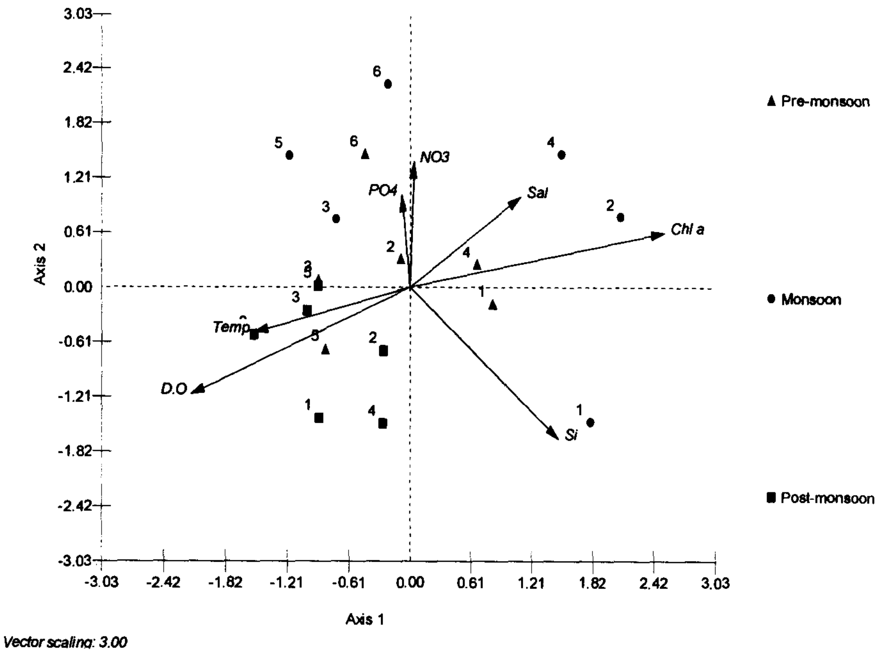


Fig. 5.11. a) Bray-Curtis similarity analysis; b) MDS for zooplankton for east coast during post-monsoon season

(a)



(b)

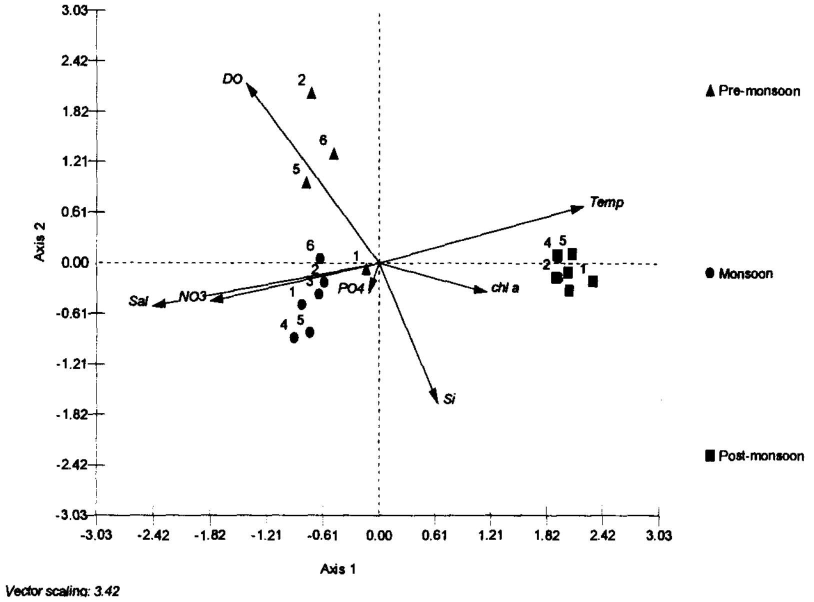
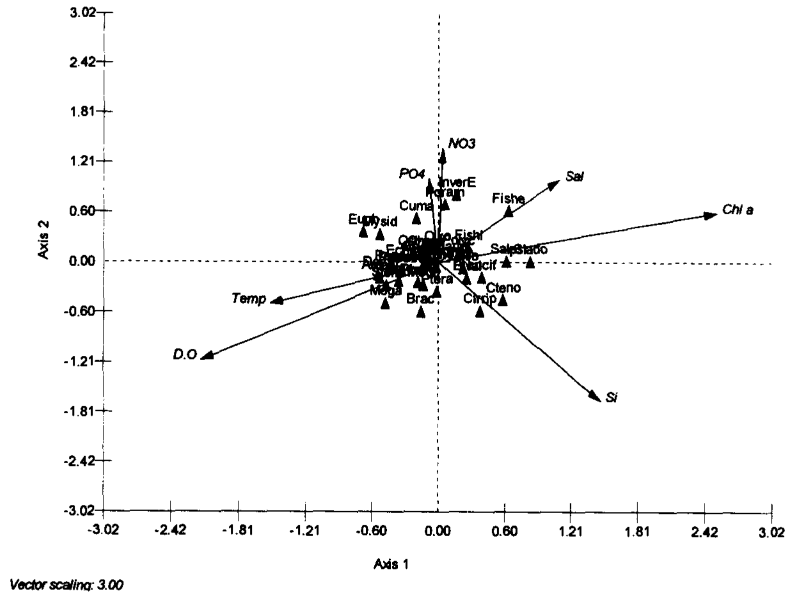


Fig. 5.12 (a,b). Ordination diagrams for stations based on Canonical Correspondence Analysis (CCA) of zooplankton data along the (a) west and (b) east coast of India. The environmental variables (temperature, salinity, nitrate, phosphate, silicate and dissolved oxygen are indicated by arrows, labelled Temp, Sal, NO3, PO4, Si and DO respectively. Station codes are given in Tables 2.1, 1-6 represents the six stations present in the respective season.

(a)



(b)

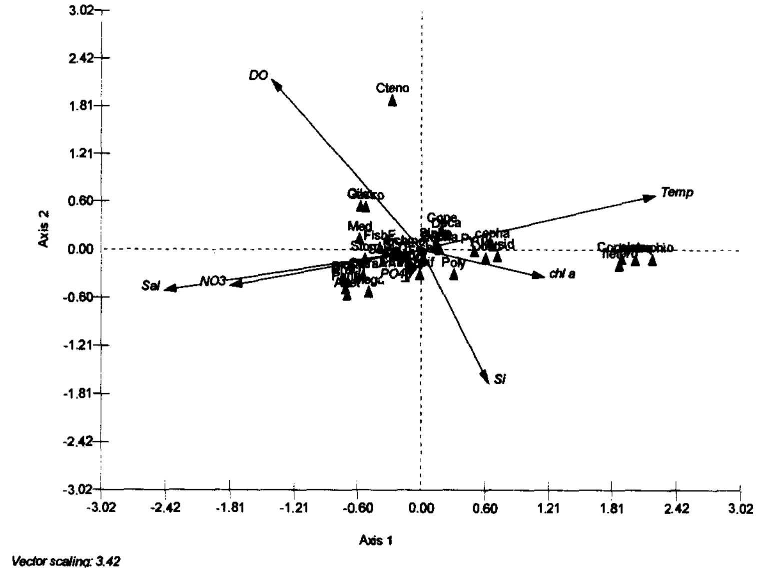


Fig. 5.13. Ordination diagrams for zooplankton groups based on Canonical Correspondence Analysis (CCA) of zooplankton data along the (a) west and (b) east coast of India. The environmental variables (temperature, salinity, nitrate, phosphate, silicate and dissolved oxygen are indicated by arrows, labelled Temp, Sal, NO3, PO4, Si and DO respectively. Station codes are given in Tables 2.1, group codes are presented in (Tables 5.17).

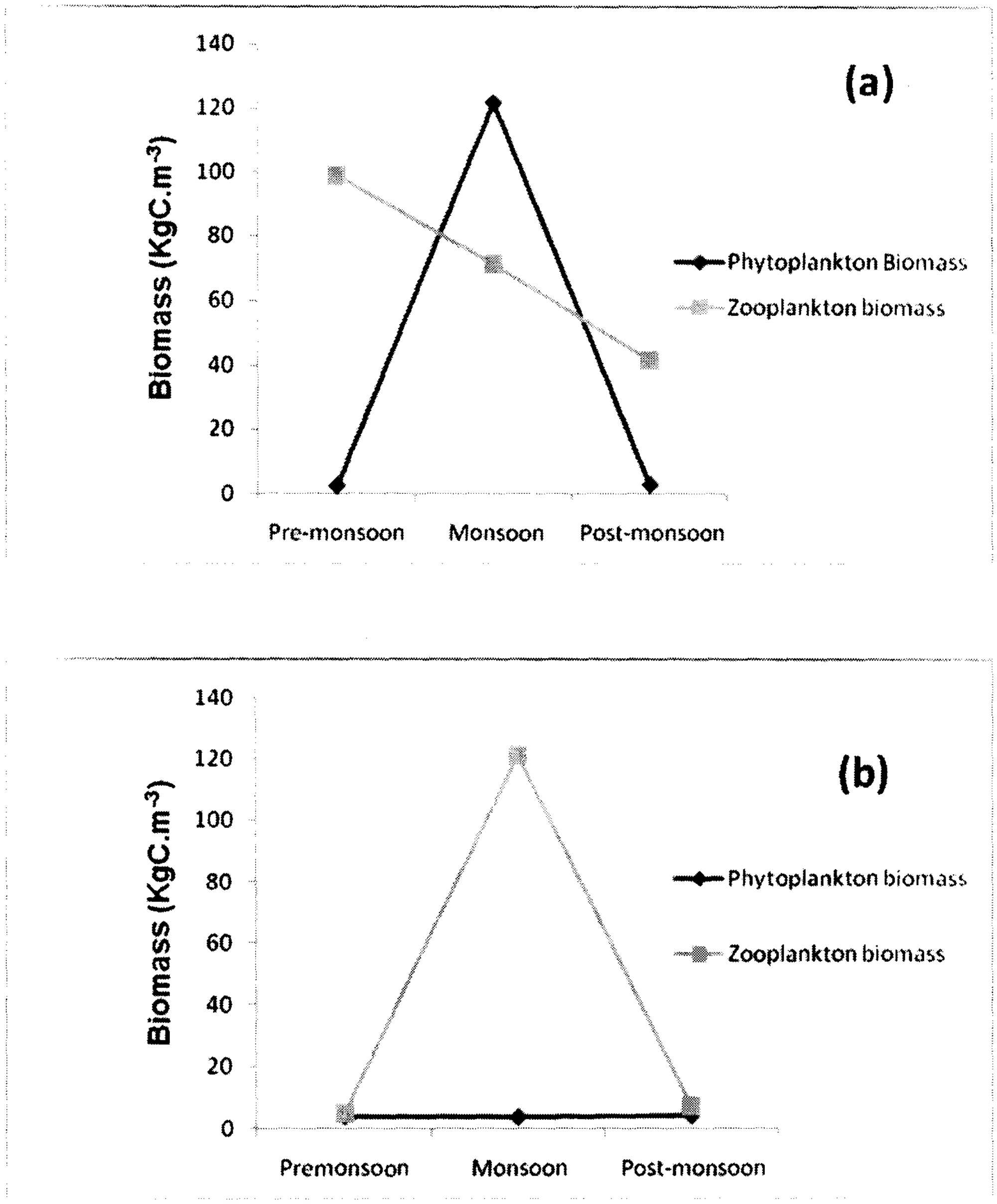


Fig. 5.14. Carbon equivalent of phytoplankton and zooplankton biomass for different seasons in the study areas along the west and east coasts

SUMMARY

Indian Ocean is one of the dynamic oceans. The northern Indian Ocean is divided in to two large basins, the Arabian Sea (AS) on the west and Bay of Bengal (BoB) on the east. The biological productivity in coastal waters of the AS and the BoB are largely influenced by the physical forcings that these basins are being subjected to, but in contrasting ways. The BoB receives large volumes of freshwater due to the opening of several large rivers during the summer, reducing the surface salinity which creates a highly stable barrier layer or stratification which prevents vertical mixing and supply of nutrients from deeper waters. The excess of precipitation over evaporation is another source of freshwater to the bay. The barrier persists although the late summer and the entire post-monsoon season which has a profound impact on the biological productivity of the BoB. The winds prevailing over BoB is not strong enough to break the barrier. Also, the upwelling in the BoB is confined nearer to the coast and only along the southern boundary during the summer. The BoB is generally considered to be low in biological productivity compared to the AS. This is mainly due to the fact that the nutrients brought in by the rivers are being removed in the deeper layers because of the narrow shelf of the bay.

The AS, on the other hand, experiences strong coastal upwelling during the summer monsoon, enriching the upper water column and thereby enhancing the biological productivity. Nutrient rich upwelled waters from the Somalia and Arabia coasts are also being transported to the central Arabian Sea, further giving an impetus to the biological productivity. In the AS, in contrast with the BoB, the evaporation exceeds precipitation and runoff and this results in the high surface salinities. With the winter cooling experiencing in the north, it leads to formation of high saline water masses that sink and replenishes the upper sub-surface layers. Further, the shallow and wide shelf facilitates mixing and enrichment of nutrients, keeping the biological productivity of the coastal waters, generally high throughout the year.

Zooplankton serve as the important trophic link in the marine food chain as it transfers energy from primary producers to tertiary producers. They mostly consume the primary producers (phytoplankton) and form the major food sources for tertiary producers. They, thus convert the plant organic matter into animal organic matter and supply to higher trophic level. Therefore, they play an important role in determining the fishery potential of any region. The mesozooplankton abundance, distribution and productivity in the Indian coastal waters are influenced by many factors, particularly the monsoons, upwelling, current reversals, oxygen depletion, salinity stratification, phytoplankton bloom etc.

The published work on mesozooplankton related to food web from the Indian waters are limited. There are no comparative studies on the mesozooplankton production between the coastal waters of the east and west coasts of India with respect to prevailing ecological conditions on seasonal basis. The present study is an attempt to understand the role of environmental factors on the distribution and abundance of mesozooplankton in the coastal ecosystem so as to identify the key parameters and also to understand the interactions between the different trophic levels. The study was carried out in the coastal region of the west coast (Goa and Mangalore coasts) and the east coast (Kakinada). The study area extends geographically from latitude $15^0 30'00''$ to $73^0 35'00''$ along the Goa coast, $13^0 00'00''$ to $74^0 38'11''$ along the Mangalore coast and $16^0 43'00''$ to $82^0 33'00''$ along the Kakinada coast. Along the Goa and Mangalore coasts, three stations along one transect each were sampled, representing 30, 50 and 100 m depth contours. Along the Kakinada coast, 6 stations were sampled two each representing, 30, 50 and 100 m depth contours. Sampling along the west coast was carried out in 2004 (January, April & September) and along the east coast in 2005

(April, September & November), representing the pre-monsoon, monsoon and post-monsoon seasons.

The study addresses the following three major objectives:

1) To study the spatial and temporal variation in the diversity of mesozooplankton in the coastal waters.

2] To understand the ecobiological influence on the distribution, abundance and productivity of mesozooplankton.

3] To evaluate the interactions between different trophic levels in relation to mesozooplankton.

Thus, the thesis presents and compares the data on the quantitative and qualitative aspects of mesozooplankton, including group diversity, seasonal distribution and relation with respect to physical, chemical and biological parameters in the coastal waters along the west and east coasts of India. The highlights of the study are listed below:

- Water Temperature ranged from 19.02 to 29.6 ^{0}C along the Goa transect and 20.6 to 30.9^{0}C along the Mangalore transect during the study period. Vertical distribution of temperature was relatively stable at both the transects during the pre-monsoon and post-monsoon seasons, but during the monsoon season, a sharp decrease was observed with depth at some stations. The lowest temperatures at both the transects were recorded during this season which was 19.02^{0}C at Stn. 3 (90 m) (off Goa) and 20.6^{0}C at Stn. 6 (90 m) (off Mangalore).
- Water temperature along the Kakinada coast ranged from 24 to 32^{0}C during the study period. A reduction with depth was observed during all the seasons, but the decrease with depth was sharp during the pre-monsoon season. Generally, the temperature

recorded along the east coast was higher than that of the west coast, particularly during the monsoon season. The Canonical Correspondence Analysis also clearly reflected the high temperature prevailing along this coast.

- Salinity ranged from 33.4 to 36.6 psu at Goa transect and 32.9 to 36.1 psu at the Mangalore transect during the study period. Salinity was more or less stable at both the transects during the pre-monsoon season while it was low at the off Goa transect during the monsoon and the post-monsoon seasons. The overall salinity was high during the pre-monsoon season and an increase with depth was noticed during all the three seasons. Along the Mangalore transect also, the pre-monsoon and monsoon values were closely similar to that of Goa transect, but during the post-monsoon season the values recorded were relatively low compared to that of the Goa transect. This could be attributed to the influence of north-east monsoon prevailing along the east coast. Increase in salinity with depth though marginal was observed at most of the stations during all the stations.
- Salinity along the east coast was relatively lower during all the seasons compared to that of the west coast. It ranged from 22.31 to 36.1 psu during the period of study. The near-surface values were generally lower compared to the near-bottom values and during the monsoon and the post-monsoon seasons it was 3-6 psu lower than the near-bottom values. No clear seasonality in salinity distribution was observed along the coasts unlike that of the west coast.
- DO ranged from 0.23 to 5.64 $ml.l^{-1}$ along the Goa transect and 0.17 to 4.79 $ml.l^{-1}$ along the Mangalore transect. Seasonal variations were observed in DO concentration at both the transects. Generally well oxygenated condition was prevailing during the pre-monsoon season at both transects. However low values were observed at a few near-bottom stations. During the monsoon season although, the DO was slightly

higher at the Goa transect, most of the sub-surface and near-bottom values showed sub-oxic levels along both the transects.

- Along the Kakinada coast, DO was generally high during the pre-monsoon followed by monsoon and post-monsoon seasons. Overall, there was a decrease in DO content with increasing depth, but the sub-oxic situation prevailing along the west coast during the monsoon season was not visible here.
- Nitrate content during the study period ranged from 0.01 to 4.97 μM at the off Goa transect and 0.003 to 5.16 μM, both high values were recorded during the monsoon season. Generally, NO_3 maxima was seen in sub-surface or near-bottom layers (shallow stations). Very low values were recorded at near-surface and mid-depths. Nitrate values were relatively higher off Mangalore transect compared to off Goa transect for the respective seasons.
- Along the Kakinada coast, generally low nitrate content was recorded at the near-surface which increased with depth during all the seasons. The NO_3 content recorded during the post-monsoon season was lower compared to other seasons. No sub-surface maxima was observed during any season.
- Phosphate content ranged from 0.01 to 3.41 μM at the off Goa transect and 0.01 to 3.83 μM at the off Mangalore transect. The ranges observed at both the transects were closely similar for the respective season, except that the highest recorded value during the monsoon season at the Goa transect was almost 3 times higher than that of Mangalore transect.
- Phosphate ranged from 0.07 μM to 5.23 μM along the Kakinada coast. No particular trend was observed in the seasonal distribution. The vertical profile however, showed

that at most of the stations, PO_4 content was relatively higher in the near-bottom layers.

- Silicate ranged from 0.01 to 20.27 μM and 0.17 to 8.27 μM along the Goa and Mangalore transects during the study period The silicate content was higher at off Mangalore transect during all the seasons compared to off Goa transect and the higher values were recorded at near-bottom waters.
- Silicate values ranged from 0.16 μM to 26.6 μM during the study period along the Kakinada coast. The overall trend observed was an increased content at the near-bottom layers.
- Chlorophyll *a* was estimated as a measure of phytoplankton biomass. It ranged from 0.05 to 8.56 mgm^{-3} at the off Goa transect and 0.04 to 5.24 mgm^{-3} at the off Mangalore transect during the period of study. The highest values at both transects were observed during the monsoon season. Generally, at all the stations and during all the seasons, a sub-surface maxima was observed, mostly at 30 m depth and at some deeper stations, at 50 m depth. The overall trend showed that chl *a* content was higher at the off Goa stations compared to off Mangalore stations. CCA analysis also indicated high chl *a* biomass along the west coast.
- Chlorophyll *a* ranged from 0.04 to 0.82 $mg.m^{-3}$ along the off Kakinada coast during the study period. It ranged from 0.06 to 0.82 $mg.m^{-3}$ during the pre-monsoon, 0.05 to 0.67 $mg.m^{-3}$ during monsoon and 0.11 to 0.78 $mg.m^{-3}$ during the post-monsoon. The range in variation between seasons was marginal, but the values were generally lower compared to those recorded along the west coast transects. One of the striking differences noticed was that the sub-surface maxima seen along the west coast transects were not visible here. Generally, the chl *a* content was relatively higher at near-surface layers.

- Mesozooplankton biomass along the Goa transect was high at 30 m stations during all the seasons and a decrease was observed with increasing depth. The highest values for all depth contours were observed during the pre-monsoon season (4.6, 4.1 & 2.1 ml.m`3, at Stn.1 (30 m), Stn. 2 (50 m) and Stn. 3 (100 m), respectively). An overall reduction in biomass was observed during the monsoon season, the highest being at Stn. 1. (3.7 $ml.m^{-3}$). The lowest biomass for the study period was recorded at Stn.3 (0.4 $ml.m^{-3}$) during the post-monsoon season.
- The highest biomass for the entire study period along the Mangalore transect, was recorded at Stn. 4 (7.1 $ml.m^{-3}$) during the monsoon season. At 100 m stations, biomass values were low during all the seasons. During the post-monsoon season, all the depth contours along this transect recorded low biomass values (0.5, 1.3 and 0.7 $ml.m^{-3}$, respectively at Stns. 4, 5 & 6).
- Biomass along the Kakinada coast ranged from 0.17 to 0.78 $ml.m^{-3}$ during the pre-monsoon season, 0.5 to 5.5 $ml.m^{-3}$ during the monsoon season and 0.28 to 0.98 $ml.m^{-3}$ during the post-monsoon season. Compared to the west cost transects, biomass recorded were very low during all the seasons.
- The faunal density was low during the post-monsoon season along the Goa transect compared to other two seasons. Total faunal density encountered were 13192, 8630 and 3717 $ind.m^{-3}$, respectively at Stns. 1, 2 & 3.
- Total faunal density were 99547, 39572 and 14122 $ind.m^{-3}$, respectively at the Stns. 4, 5 & 6 during the monsoon season along the Mangalore transect. All these values were higher compared to the same seasons for the respective depth contour of Goa transect.
- Faunal density recorded at all the stations along the Kakinada coast was considerably lower than that of Goa and Mangalore coasts. Relatively higher diversity was observed during the monsoon season.

- General composition of various taxa/groups remained more or less similar along both the costs during all the seasons. However, Copepod was the single largest group, constituted >60% of the total faunal density at all the stations during all the seasons. At some stations its contribution was 80-90%. Ostracods, cladocerans and oikopleura were other groups which contributed significantly to the population.
- Bray-Curtis analysis was performed to identify the cluster of stations having similarity with respect to the group composition. Distinct groups were recognised for different seasons. MDS also brought out the similar type of grouping, thereby confirming the existence of the various clusters. Simper analysis could distinguish those groups which were associated with the dissimilarity between the clusters. Copepods, ostracods, oikopleura, polychaetes etc. were the major groups identified for the dissimilarity.
- The systematic status of the 33 identified zooplankton taxa/groups was examined and a list was provided.
- In order to understand the energy available at the primary trophic level (phytoplankton) and the energy requirement at the secondary trophic level (zooplankton) in the study area along the east and west coasts, the phytoplankton biomass (Chl *a*) and the zooplankton biomass were converted to respective carbon equivalent for each study area, separately for each season. The phytoplankton biomass calculated for the study area along the west coast for different seasons were, 2.42 and 2.7 $KgC.m^{-3}$ for the pre-monsoon and post-monsoon seasons respectively, while the same for the monsoon season was 121.5 $KgC.m^{-3}$ which is >50 times the other two seasons. The annual biomass sustained was estimated to be 42.2 $KgC.m^{-3}$.
- A more uniform pattern of phytoplankton carbon availability was noticed for the east coast during different seasons. It was 3.9 $KgC.m^{-3}$ for pre-monsoon, 3.8 $KgC.m^{-3}$ for

monsoon and 4.3 KgC.m^{-3} for post-monsoon seasons. The annual biomass available was 4.04 KgCm^{-3}.

- The zooplankton biomass estimated for the seasons along the west coast were, 98.6 KgC.m^{-3} for the pre-monsoon season, 70.9 KgC.m^{-3} for the monsoon season and 41.3 KgCm^{-3} for the post-monsoon season. The annual contribution of zooplankton carbon for the 50 m water column of the study area was estimated to be 70.3 KgC.m^{-3}.
- The zooplankton carbon estimated for the water column for the three seasons were 4.7, 102.8 and 7.2 KgC.m^{-3}, respectively for pre-monsoon, monsoon and post-monsoon. The biomass sustained on an annual basis was 38.2 KgC.m^{-3} which was almost half that of the west coast.
- The phytoplankton and zooplankton biomass for the different seasons indicated that only during the monsoon season autotrophy was prevalent along the west coast when mesozooplankton could sustain the energy requirement through phytoplankton biomass since phytoplankton biomass available exceeded the energy requirement of zooplankton. However, during pre- and post-monsoon seasons, the available zooplankton carbon (98.6 and 41.3 KgCm^{-3}) far exceeded the availability of phytoplankton biomass and therefore mesozooplankton may have to feed on available alternative food sources such as microzooplankon, since the phytoplankton biomass prevailing was not sufficient to sustain the zooplankton biomass. The results thus indicate that the autotrophy was prevailing only during the monsoon, while during the pre- and post-monsoon seasons, heterotrophy was more common. In other words, it was only during the monsoon season that phytoplankton biomass was available in excess to support the requirement of zooplankton standing stock. During the other two seasons, the phytoplankton biomass was insufficient to sustain the zooplankton biomass and therefore, the latter had to feed on other sources such as attached

bacterioplankton, microzooplankton or suspended organic matter etc. whichever was available.

- A contrasting trophic relationship was observed along the east coast. Here, autotrophic relationship was not observed during any season, but heterotrophic relationship was prevailing during all the seasons. Although the extent was low during the pre- and post-monsoon, it was conspicuously high during the monsoon season. It therefore, suggests that the zooplankton biomass along the east coast is not wholly supported by the availability of phytoplankton biomass, but these organisms sustain on alternate sources of energy during all the seasons and more so during the monsoon season.

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