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 πλαντος ("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 (e.g., 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 (e.g., 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 survey 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 meteorological 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.


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

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


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 at the 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 along 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°30’00’’ to 73°35’00’’ along the Goa coast 13°00’00’’ to 74°38’11’’ along the Mangalore coast (Fig. 2.1), and 16°43’00’’ to 82°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 coast). 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)