Mesozooplankton of the Arabian Sea and the Bay of Bengal with special reference to planktonic ostracods

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by

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Declaration

I hereby declare that the thesis entitled **"Mesozooplankton of the Arabian Sea and the Bay of Bengal with special reference to planktonic ostracods"** is an authentic record of the research carried out by me, under the supervision of Dr. Saramma U Panampunnayil, Scientist F, National Institute of Oceanography, Regional Centre, Kochi- 18, in partial fulfillment of the requirement for the Ph.D Degree of the Cochin University of Science and Technology under the faculty of Marine Sciences and that no part of this has been presented before for any other degree, diploma or associateship in any university.

(P. Jasmine)

Kochi-18
16-01-2009

Certificate

I herby certify that the thesis entitled **"Mesozooplankton of the Arabian Sea and the Bay of Bengal with special reference to planktonic ostracods"** submitted by P. Jasmine, Research scholar (Reg. No. 2731), National Institute of Oceanography, Regional centre, Kochi-18, is an authentic record of research carried out by her under my supervision, in partial fulfillment of the requirement for the Ph.D Degree of the Cochin University of Science and Technology in the faculty of Marine Sciences and that no part thereof has been previously formed the basis for the award of any degree, diploma or associateship in any university.

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P. Jasmine

Dedicated to

my family…

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List of Acronyms

AS	Arabian Sea
ASHSW	Arabian Sea High Salinity Watermass
BoB	Bay of Bengal
BoBPS	Bay of Bengal Process Studies
CTD	Conductivity- Temperature- Depth
e.g.	exempli gratia (Latin word meaning ‘for the sake of example’)
EEZ	Exclusive Economic Zone
EICC	East India Coastal Current
et al.	et alii (Latin word meaning ‘and others’)
etc	et cetera (Latin word meaning ‘and other similar things; and so on)
FORV	Fisheries and Oceanographic Research Vessel
GF/F	Glass Fibre/Filter
GLOBEC	Global Ocean Ecosystems Dynamics
IIOE	International Indian Ocean Expedition
IMC	Indian Monsoon Current
JGOFS	Joint Global Ocean Flux Studies
MLD	Mixed Layer Depth
MR-LR	Marine Research Living Resources
N	North
NE	Northeast
NEC	North Equatorial Current
NIO	National Institute of Oceanography
ORV	Oceanographic Research Vessel
PGW	Persian Gulf Watermass
PP	Primary productivity
RSW	Red Sea Watermass
SEC	South Equatorial Current
SMC	South West Monsoon Current
SSS	Sea surface salinity
SST	Sea surface Temperature
SW	South West
UNESCO	United Nations Education, Scientific and Cultural Organisation
viz	videlicet (Latin word meaning ‘namely’)
WICC	West India Coastal Current
WMC	Winter Monsoon Current
WOCE	World Ocean Circulation Experiment

Chapter - 1

INTRODUCTION

Marine resources are being increasingly affected by human activities and the fate of the Indian Ocean is of no exception. India's increasing population underlines the need for conservation of marine resources for its sustainable utilization (IUCN, 1990; WRI, 1992). With an estimated coastal population of 70 million, ideally the country requires 13 million tonnes of fish against the present production of 3.9 million tonnes. Estimates of the potential fishery resources from the Indian EEZ (2.02 million km^2) vary from 3.5 to 4.7 million tonnes per year, which is the fourth highest in the world. The recent annual fish landings from the Indian seas have ranged between 2.2 and 2.8 million tonnes, leaving ~1 million tonnes untapped from the offshore regions. There is over exploitation of many of the fish stocks in the inshore regions, which are being caught beyond the sustainable levels of exploitation. However, deep-sea fishery resources are very much under-utilized from Indian EEZ, but these can only be economically harvested, if the fishing grounds are located precisely. An essential pre-requisite for predicting where such grounds might be located, is a comprehensive scientific data base of primary and secondary productions in this area. Thus, studies quantifying secondary productivity (zooplankton) of these areas have great significance in characterizing their bio-resources.

The Arabian Sea (AS) and Bay of Bengal (BoB) are the two basins of the Northern Indian Ocean that border the Indian peninsula. The Arabian Sea to the west is an evaporative basin with monsoon-driven upwelling. The Bay of Bengal to the east can be characterized as an extended estuarine basin. Despite experiencing identical tropical climate, these two basins are widely different in terms of their physical, chemical and biological characteristics. Moreover, the composition of marine landings significantly changes, not only between the east and west coasts, but also within each region. In order to get a better insight into the trophic structure of the AS and BoB, seasonal studies are especially important in areas where environmental conditions progressively change. So the study of plankton is fundamental to explaining both the observed dramatic reductions in the abundance of fish and predicting the impact of environmental changes on fish stocks, in these regions.

Plankton is the predominant community in all oceans. Phytoplankton plays a vital role in generating the food to secondary trophic level (zooplankton), which in turn transfers this energy to tertiary trophic level (Fish). So understanding the zooplankton is an important component in our attempts to estimate and manage the fishery potential of our seas. The present study provides an insight in to the seasonal regulation and trophic role of mesozooplankton in the Arabian Sea and Bay of Bengal.

Among the zooplankton, ostracods are numerically the second-most abundant taxonomic group after copepods. They are often, numerically subdominant in mesozooplankton samples, particularly in subthermocline waters of all oceans, but in the Indian Ocean they are also important in the wind-mixed layer above the thermocline. Only a few earlier reports have addressed the distribution and species composition of ostracods in the Indian waters. This study makes a contribution towards understanding the diversity of planktonic ostracods in the AS and BoB.

1.1 Plankton

The marine organisms can be categorized into three major components – plankton, nekton and benthos. Plankton consists of drifting or free-floating organisms that inhabit the pelagic zone of oceans, seas, or fresh water. In marine environment plankton is the major food source for higher organisms and so plays a vital role in the marine food chain. The term 'Plankton' was coined by the German researcher Victor Hensen (1887). It is derived from the Greek word 'Planktos' meaning wanderer or drifter' with limited movement. Nekton are those animals with active swimming capabilities, and includes larger organisms such as the fishes. Benthos includes those organisms that live in/on the seabed whether it is a hard or soft substrate.

The term plankton encompasses the zooplankton, the phytoplankton and the bacterioplankton (Day Jr. *et al.*, 1989). Phytoplankton are predominantly small unicellular autotrophic prokaryotic or eukaryotic algae that live within the upper levels of the water column where there is sufficient light to support photosynthesis. Zooplankton may be defined as the community of all phagotrophic organisms (Lenz, 2000), and includes representatives from most phyla of the animal kingdom. Zooplankton consists of heterotrophic organisms that range in size from small protozoans to quite sizeable metazoans (some are very large such as the gelatinous species of salps and cnidarians). Many of the larger zooplankters are capable of swimming short distances, and many migrate vertically from tens to hundreds of meters. The smaller species have limited mobility and depend more on water turbulence to stay afloat. All zooplankton, however, lack the ability to maintain their position against the movement of large water masses. Zooplankton are the primary consumers of phytoplankton and form a vital link between the phytoplankton and the higher consumers including fish, shellfish, birds and mammals

There is a great diversity of plankton, so there are different ways of classifying them according to size, type and life history (Sieburth, 1978; Omori & Ikeda, 1992). For example, size categories include Femto plankton (0.02-0.2 µm), Picoplankton (0.2-2 µm), Nanoplankton (2–20 µm), Microplankton (20–200 µm), Mesoplankton (0.2–20 mm), Macroplankton (20–200 mm), and Megaplankton (>200 mm). These categories encompass the functional groupings of bacterioplankton, phytoplankton and zooplankton.

According to life history characteristics, zooplankton can be divided in three broad categories: holoplankton, meroplankton and tycoplankton (Raymont, 1983; Omori & Ikeda, 1992). Holoplankton are those species which spend all stages of their life cycle in the water column, such as calanoid copepods, euphausiids, ostracods and appendicularians. Meroplankton is the term applied to the large array of animals that live as free swimming planktonic organisms only during the early part of their life cycle, and includes the eggs and/or larval stages of many benthic and nektonic species (Lenz , 2000). The tycoplankton occur predominantly in shallow waters especially in estuaries and includes those animals, such as mysids and other crustaceans that spend just part of the day/night cycle as plankton, and also includes normally benthic species that are swept into suspension from the bottom by strong current or storms, such as some harpacticoid copepods, gammarid amphipods, cumaceans, isopods etc. (Raymont, 1983).

1.2 Mesozooplankton

Mesozooplankton generally consists of the crustaceans, pteropods, gelatinous plankton and meroplanktonic larvae including fish eggs, and larvae (Plate. 1.1) that are normally sampled with nets with 200-500 µm mesh. Crustaceans are the major component and are represented by eight orders, viz, cladocerans, ostracods, copepods, cirripeds, mysids, amphipods, euphausiids and decapods. The gelatinous zooplankton comprises of various taxa such as cnidarians (hydromedusae, siphonophores and scyphomedusae), ctenophores and pelagic tunicates (pyrosomes, doliolids, salps and appendicularians).

In the ocean, abundance and distribution of mesozooplankton varies horizontally, vertically and seasonally, and are strongly dependent on factors such as physical state of water column, ambient nutrient concentrations, temperature, and trophic status of that area. Oceanic zooplankton is characterised by the presence of distinct vertical migrators. The epipelagic (0-200 m) and mesopelagic zones (200-1000m) are the main domains of zooplankton and their biomass decreases logarithmically with depth (Vinogradov, 1997).

1.3 Planktonic Ostracods

Among the mesozooplankton, planktonic ostracods are numerically ranked second to copepods (Plate. 1.3). They are deep dwelling diel migrators and detritus feeders. Planktonic ostracods have not received much attention in ecological studies, in spite of their relatively high abundances, at all depths and importance in recycling material in pelagic ecosystems (Angel, 1999). To date, 209 species of halocyprids and 8 myodocopid species of ostracods have been described from oceanic waters. In addition, there are 34 species of the family Thaumatocyprididae, which are either benthic or cavernicolous. The majority of the marine species of planktonic ostracods are halocyprids; occurring almost everywhere from the surface to deep water. However, at higher latitudes (>50°) despite being very abundant in deeper waters, they are seldom encountered in the upper 100-200 m of the water column (Williams, 1975). They are relatively small in size (0.5 - >3 mm). Most of the halocyprids species are detritivores, seemingly adapted to exploit marine snow and other sinking particles. Studies on the ostracod reproduction (Cohen and Morin, 1990a) have shown that their life spans range from a few months to four years.

The taxonomic hierarchy of planktonic ostracods is as follows.

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Ostracoda
Subclass	Myodocopa Sars, 1866
Order	Halocyprida Dana, 1853

The planktonic ostracods belong to the subclass Myodocopa, and most belong to the order Halocyprida, which lack obvious eyes. A few of them belong to the order Myodocopida Sars, 1866, which either have lateral compound eyes (*Macrocypridina*) or large central naupliar eyes with parabolic reflectors (*Gigantocypris*). Ostracods have their body enclosed within a carapace (shell) and when mature, have seven pairs of limbs. Juvenile instars have either fewer or partially developed limbs. The structural details of the halocyprids are shown in Plate 1.3. Carapace consists of two valves that are hinged along the dorsal line. Carapace shape ranges from globular to cylindrical or even laterally compressed. In majority of genera, the anterior of each valve is developed into a rostrum that overlies and protects the first antennae and frontal organ. There is a large group of gland cells on each carapace valve, which are of taxonomic importance. Characteristically males have a group of gland cells on each valve just below the posterior dorsal corner. These glands probably release luminescent secretions into the respiratory flow of water.

The largest limbs are the second antennae and consists of the muscular protopodites that generate the power for swimming. On the inner surface of the protopodite is an endopodite, which is sexually dimorphic. Between the protopodites are the two first antennae, and the frontal organ. Both the first antennae and the frontal organ are sexually dimorphic. Posterior to the second antennae and flanking the mouth are a pair of mandibles, with well-developed endopodites that are used to ingest food. Maxillae show minor differences in the numbers of setae between the various genera and hence are not used in species identification. The exopodites manipulate food particles at the mouth. Fifth pair of limbs manipulates food particles between the gape of the carapace valves. In males, the sixth pair of limb is strongly developed. Seventh pair of limbs are vestigial in halocyprids and are reduced to two segments with the terminal segment carrying two unequal setae. In contrast in myodocopids, the seventh pair of limbs are multi-segmented and carries an elaborate array of bristles. They continuously writhe around over the surface of the abdomen, possibly cleaning the inner surfaces of the carapace. Caudal furca consists of two flanges which are usually armed with 8 pairs of hook setae. The number of these caudal spines increases with each developmental ecdysis. The earliest juvenile instars have just two pairs of hook setae with an additional pair added at each moult. So at maturation after the six ecdyses, the adult has eight pairs of claw setae.

In male halocyprids the copulatory appendage is a single structure located on the right side of the caudal furca. In myodocopids, the copulatory appendage is a paired structure that is placed symmetrically at the base of the furca, as there is no sign of asymmetry in the structure of the limbs and carapace.

1.4 Importance of ostracods

Planktonic ostracods are one of the major components of the mesozooplankton community, found in freshwater and marine environment. They are regular constituents of zooplankton community and at times, they swarm (Plate 1.4). They serve as basic food for most of the fishes like lesser sardines, white pomfret, anchovies and most of the myctophid fishes besides providing an important contribution in recycling of materials in pelagic ecosystems (Angel, 1999). They are laterally compressed organisms, as their body is enclosed in a bivalve carapace made up of magnesium calcite, and are resistant to destruction after the death and therefore, are preserved in fossil. Most of the myodocopid ostracods carapaces are a source of calcium in marine sediments. So it is an important group of organisms to be studied in the field of paleontology (Kulkoyluoglu, O., 1999). In freshwater, the ostracod *Cypretta,* is an effective predator of *Biomphalaria glabrata*, a vector snail of the blood fluke that causes the disease schistosomiasis (Sohn and Kornicker, 1972). Ostracods are particularly useful in the biozonation of marine strata, on a local or regional scale as indicators of ancient shorelines, salinities and relative sea floor depths. These marine species are also useful for defining ocean temperature and dissolved oxygen (Longhurst, 1967; Antezana, 2002) and some species of ostracods are indicators of water masses (Fasham & Angel, 1975; Jasmine et al., 2007). Martens (1981) observed *Conchoecetta giesbrechti* as an indicator of Equatorial Subsurface Water (ESSW). Some species of the ostracods (Plate I.5) are bioluminescent (Harvey, 1952; Angel, 1968, 1972; Cohen and Morin., 2003) and are useful in biophotonic research, *i.e.* bioluminescent genetic markers can have more advantage over Ca+ based fluorescent dyes (for easily targeting to specific cells and sub cellular compartments) in molecular research.

1.5 Role of mesozooplankton in the pelagic foodweb

Zooplankton constitutes a major component of marine ecosystems, providing the link between the primary production and higher trophic levels *i.e.,* transfers the organic energy trapped by unicellular algae through photosynthesis to higher trophic levels. The availability of zooplankton as a food of the right size, right place and time during different feeding periods of fish larvae, constitutes the famous mismatch hypothesis. Zooplankton are essential for the growth of microbial populations through their release of exudates and excretes in particulate and dissolved form. They also play a major role as consumers (Longhurst, et al., 1989). Because of this, zooplankton form an integral component of marine food chain, both from economic and ecological perspectives.

The world's oceans act as a carbon pump by removing carbon from the surface waters to the bottom, through both physico-chemical and biological processes (Longhurst, 1991). The fixation of inorganic carbon into organic matter during photosynthesis, its transformation through food webs (trophodynamics), physical mixing, transport and gravitational settling are referred to collectively as the "biological pump" Mesozooplankton are the consumers of phytoplankton, and have a significant impact on the oceanic biogeochemical cycles of carbon and other elements. Their contribution to the sinking particle flux is therefore much larger than that of microzooplankton. The biological pump (Plate 1.2) involves the production of organic carbon derived from phytoplankton through photosynthesis, the sinking and decomposition of animal debris, and the grazing and migratory behaviour of zooplankton (Longhurst, 1991; Fortier et al. 1994; Falkowski et al., 1998). The sinking of dead/senescent phytoplankton cells (von Bodungen et al., 1986) and the feeding activity (herbivory or carnivory) of zooplankton (Longhurst & Harrison, 1989; Longhurst, 1991) are the major pathways for the transfer of carbon to depth. Zooplankton play a well-documented role in the biological pump by feeding in surface waters and producing fast-sinking faecal pellets particularly in deeper water after vertical migration (Angel, 1985; Sherr & Sherr, 1988; Longhurst, 1991; Fortier et al., 1994; Froneman, 1995). Vertically migrating zooplankton and nekton consume organic particles in the surface waters at night and metabolize the ingested food below the mixed layer during the day. The passive sinking of feacal pellets and active transport via diel vertical migration are important (Angel, 1985; Fowler & Knauer, 1986) in the fluxes of carbon from the surface to the deep ocean. Thus, zooplankton plays an integral role in the export of material from euphotic zone (Dam et al., 1995; Le Borgne & Rodier, 1997). The overall effect of these biological processes is a sink of carbon dioxide (CO_2) in surface waters, thereby resulting in the drawdown of atmospheric CO_2, along a concentration gradient from the atmosphere to the surface water of the ocean (Longhurst, 1991; Siegenthaler & Sarmiento 1993).

On the other hand, the retardation of vertical flux resulting from the activity of mesozooplankton is under studied, but potentially is an important process. Hydrodynamically mediated injections of nutrients into the surface layers can lead to the development of massive phytoplankton blooms, which can function to remove most of the nutrients from the upper mixed layer through aggregation and subsequent sedimentation. Thus the collapse of massive phytoplankton blooms can result in a crash in the biomass of the zooplankton communities. Flux feeding (Glimer & Harbison, 1986., Jackson, 1993) and coprophagous mesozooplankters (Paffenhofer & Knowles, 1979; Noji et al., 1991) help to recycle and hence conserve organic and inorganic substance in the euphotic zone, and also facilitates their remineralization in the water column and reduces losses from the euphotic zone by vertical flux. Thus the retardation of vertical flux due to mesozooplankton activity helps to prevent declines in plankton communities. This may be important for the maintenance of plankton biomass in the mixed layer particularly during periods of stratification.

1.6 Review of Literature

Considerable effort has been devoted over the years to understand the hydrography and the circulation pattern of the Arabian Sea in relation to the monsoon forcing on the seasonal upwelling and primary production, by the international expeditions like IIOE (1960-1965), WOCE (1992-1993), GLOBEC (1993) and JGOFS (1995-1997). The seasonally reversing monsoon winds are primarily responsible for the hydrographic variations and circulation in the upper ocean dynamics of the AS (Banse, 1987; Bauer et al., 1991; Shankar et al., 2002). Studies on the circulation and upwelling patterns along the west coast of India have been studied by Banse, (1968) Shetye et al (1990, 1991), Muraleedharan et al (1995). Upwelling along the west coast of India and the associated biological production has been explained by Banse (1987). Arabian Sea-Joint Global Ocean Flux Studies (JGOFS) provided substantial amount of information on the physical forcing and biological production in the AS (Madhupratap et al., 1996a; Smith 1998; 1999; 2001; Prasanna Kumar et al., 2001a; 2001b; Barber et al, 2001). The comparatively high photosynthetic activity in the AS leads to a greater concentration of the dead cells and detritus at the thermal discontinuity layer, which consume oxygen during decomposition (Sen Gupta et.al., 1976). The supply of oxygen to the waters below the euphotic zone is restricted by the strong density gradient and poor horizontal advection and results in severe depletion of oxygen below the thermocline and at intermediate depths (Naqvi and Qasim, 1983). The oxygen minimum zone (OMZ) and its relation to zooplankton in the Arabian Sea have been studied by Vinogradov & Voronina (1961). Studies using the satellite derived images and mixed layer models found a significant correlation between SST and chlorophyll *a* biomass in AS (Shetye 1986; Sathyendranath et al., 1991; Nakamoto et al., 2000). A major feature observed in the northern Arabian Sea during November–February, is the cold, dry continental air blowing into the Arabian Sea causing winter cooling (SST ~ 24°C), densification and sinking of surface waters. This in turn, leads to deep MLD and the convective mixing up of nitrate into the surface layers (2–4 μM) to accelerate biological production (Banse & McClain, 1986; Madhupratap et al., 1996a,b; Kumar & Prasad, 1996; Jyothibabu et al., 2003; Balachandran et al., 2008). Heterotrophs, like *Noctiluca,* regularly bloom both during and immediately after the monsoon, following diatom blooms (Madhupratap, 1993). The southwest monsoon forces upwelling along the west coast of India, supporting diatom blooms and appearance of a large shoals of *Sardinella longiceps*, the oil sardine, which feeds directly on the diatoms (Madhupratap et al., 2001). On the other hand, regular and spectacular blooms of blue-green algae (*Trichodesmium*) occur all over the northeast and southeast Arabian Sea during February-May (Devassy et al., 1978).

The zooplankton of the Arabian Sea region is known primarily from three oceanographic expeditions: the John Murray Expedition (JME; 1933 1934), the International Indian Ocean Expedition (IIOE; 1960-1965), and the Index Expedition (1979). Zooplankton studies of the west coast of India have been described by Panikkar (1970); Rao (1979); Madhupratap & Haridas, (1990); Madhupratap et al.,(1990); Mathew et al.,(1990a, b); Madhupratap et al., (1992); Padmavathy et al.,(1998); Madhupratap et al., (2001). Most of the studies reported elevated mesozooplankton biomass was during the southwest monsoon. Madhupratap et al., (1992) reported that there is only a small difference in biomass between monsoon and non-monsoon seasons off the north western coast of India. The vertical distribution of biomass in the Arabian Sea is greatly influenced by a suboxic zone that extends roughly from 200 m to 1500 m (Vinogradov, 1970; Wyrtki, 1971). Most of the mesozooplankton are restricted above the suboxic region (Vinogradov, 1970; Paulinose & Aravindakshan, 1977). The vertical zonation of zooplankton in the northern AS from the coastal and open ocean waters have been described by Smith, (1982); Madhupratap and Haridas, (1990); Madhupratap et al., (1990); Paulinose et al., (1992); BottgerSchnack, (1994, 1996); Madhupratap et al., (1996b); Koppelmann and Wiekert (1997)., Padmavathy et al., (1998) and Wishner et al., (1998). The finding of a 'paradox' for the northern AS was with regard to the mesozooplankton biomass remaining almost invariant despite seasonal variations in the primary productivity (Madhupratap et al., 1992, 1996a, b; van Cowelaar, 1997; Baars, 1999). These observations have resulted in the perception that the Arabian Sea shifts between a highly productive upwelling dominated situations during the southwest monsoon, and an oligotrophic condition during the spring and fall intermonsoons. While this characterization may be generally true, much of the details are lacking concerning the magnitude of seasonal shift in the abundance and biomass of mesozooplankton and their relation to various physico- chemical processes.

The physical characteristics of the BoB has been described by La Fond, (1957); Suryanarayana et al, (1991); Murty et al., (1992a, 1992b); Subramanian, (1993)., Shetye et al., (1991b, 1993, 1996); Sarma et al., (1999); Gopalakrishna et al., (2002) and Babu et al., (2003). The thermohaline stratification in the northern BoB causes a thick barrier layer, which inhibits entrainment of nutrients back up into the photic zone (Pankajakshan et al., 2007a). Upwelling in the BoB is very weak, but cyclonic storms enhance chlorophyll biomass and primary production (Rao and Sastry, 1981; Madhu et al., 2002; Vinayachandran and Mathew, 2003). However, the massive freshwater influxes result in strong vertical stratification, which impede the vertical transfer of nutrients to the surface, leading to low biological production. Gomes et al., (2000) examined the influence of physical processes on the seasonal bloom of phytoplankton in the BoB. Murty et al. (2000) related the subsurface chlorophyll maxima to the vertical stability of the water column in the BoB. The Bay of Bengal Process Studies (BoBPS) programme documented the low productive nature of the bay using simultaneously measured data on physical, chemical and biological parameters during the SW monsoon (Madhupratap et al., 2003; Prasanna Kumar et al., 2002). They found that strong stratification caused by the freshwater input prevented the replenishment of nutrients that constrained the primary productivity. However, very few studies have addressed the influence of physical forcing on biological production in the BoB (Banse, 1999). Most of the biological studies in the BoB have focused mainly on the seasonal variation in primary productivity and to some extent, on the abundance and composition of mesozooplankton (Panikkar & Rao, 1973; Nair et al., 1981; Achuthankutty et al., 1980; Madhupratap et al., 2003). Recently, three concurrent processes (Muraleedharan et al., 2007) has been reported to occur during the summer monsoon (anti-cyclonic warm gyre in the south, coastal upwelling and a cyclonic eddy in the north) that differentially influence the biological production and mesozooplankton structure of the BoB.

Studies on marine ostracods gained considerable momentum in the middle of the 19th century; the most important being Claus (1891 and 1894); Brady & Norman (1896) and Muller (1890, 1894, 1906a, 1906b, 1908 and 1912). They published a series of papers devoted almost entirely to describing the diagnostic features of the ostracods. Cannon (1940) published a list of planktonic ostracods collected during John Murray expedition (1933-1934). Skogsberg (1920, 1931); Sars, (1928); Iles, (1953 & 1961); Angel, (1968a, 1968b, 1969a, 1969b, 1969c, 1969d, 1970 & 1974) and Poulsen, (1962, 1969a, 1969b & 1973) have published detailed information on their morphology and distribution which are helpful in taxonomy. The information on the Indian Ocean halocyprids is mainly confined to Müller's (1906a) work on Valdivia material and Poulsen's (1962,1969, 1973) work on Dana material, which had covered only a few stations, mainly from off Sumatra and in the Central and western Indian Ocean. Recently, George (1968, 1975); James, (1972, 1973); George and Nair, (1980); Mathew et al., (1980); Nair and

Madupratap, (1984), Mathew et al., (1996) have published papers on planktonic ostracods in the Northern Indian Ocean. However, planktonic ostracods have received scanty attention in ecological studies (Angel, 1999). Most of the ecological studies have been done in the Chilean waters (Martens, 1979, 1981), Atlantic (Angel, 2007) and in Humbolt Current off Peru (Castillo, 2007). In the Indian Ocean, in spite of their abundances, no detailed ecological studies have been undertaken on planktonic ostracods till now. Also no attempt has hitherto been made for a comprehensive study that involves both the AS and BoB.

Most of the zooplankton studies around India have been limited to the western Arabian Sea, whereas the mesozooplankton studies in the BoB are scanty. An overview of the distribution, composition and vertical migration of mesozooplankton based on the spatio- temporal scale in the AS and the BoB as a whole, is needed to explain the vertical carbon flux and its relation to the biogeochemical interactions.

1.7 Scope and Objectives

The Arabian Sea and the Bay of Bengal are both highly dynamic ecosystems, due to the seasonally reversing monsoon winds, but the processes affecting the mesozooplankton community remain poorly understood. These are important basins exhibiting enhanced biological production as a result of upwelling, winter cooling and other episodic events such as eddies and gyres. Zooplankters are primarily the prey for almost all fish larvae. Seasonal changes in the biogeochemical processes can strongly affect zooplankton density and distribution, which in turn, strongly affect the larval growth, and consequently, the pelagic fish recruitment. It is clear that plankton biomass and biogeochemical fluxes are not in steady state. Acoustic data on mesozooplankton abundance suggests that they also exist in the mesopelagic zone. Earlier studies were confined only to the upper 200 m and hence the structure of mesozooplankton community in the deeper layers was not well known. Copepods are the dominant mesoplankton group, and therefore the majority of the studies were focused on them. The planktonic ostracods are the second major crustacean group and at times, their swarms can outnumber all other planktonic groups. The understanding of the community structure of the ostracods is essential to establish their role in the marine food web. Mesozooplankton is responsible for the vertical flux of organic matter produced by phytoplankton and is assumed to be equivalent to new production (Eppley & Peterson, 1979). Since the fate of newly produced organic matter depends upon their consumers, the zooplankton biomass must be estimated in size fractions or taxonomic components to understand the vertical flux of organic carbon. It is thus important to update our knowledge on different groups of zooplankton on the basis of seasonal and temporal distribution. The distribution in space and time is essential for modeling the carbon cycling that structure the marine ecosystems. This thesis focuses on two interdependent aspects:-

1. It provides information on the patterns of abundance and vertical distribution of mesozooplankton over a broad spectrum of physical conditions in the Arabian Sea and the Bay of Bengal and their response with various biogeochemical processes.
2. It provides a detailed account on the abundance, seasonal variation in species composition and swarming behaviour of ostracods in relation to the physical, chemical and biological properties of the sea water.

The main objectives of the study are,

To investigate the mesozooplankton standing crop in the Arabian Sea and Bay of Bengal and its seasonal variation.

To study the response of mesozooplankton to various physical processes such as upwelling, cyclonic eddy, warm gyre etc.

- To compare the coastal and open ocean variability in the mesozooplankton of the two basins

To study the vertical migration of mesozooplankton in the Arabian Sea and Bay of Bengal and its implications on the carbon cycling.

To investigate the qualitative and quantitative distribution and diversity of ostracod species.

To Identify the bioluminescent species of ostracods.

The thesis has been divided in to **Seven** chapters viz. Chapter **1:** Introduction, Chapter **2:** Materials and Methods, Chapter **3:** Mesozooplankton of the Arabian Sea, Chapter **4:** Mesozooplankton of the Bay of Bengal, Chapter **5:** Diel vertical migration of Mesozooplankton in the AS and BoB, Chapter **6:** Ostracod Diversity in the AS Chapter **7:** Ostracod Diversity in the BoB. This is followed by the Summary & Conclusion and Bibliography.

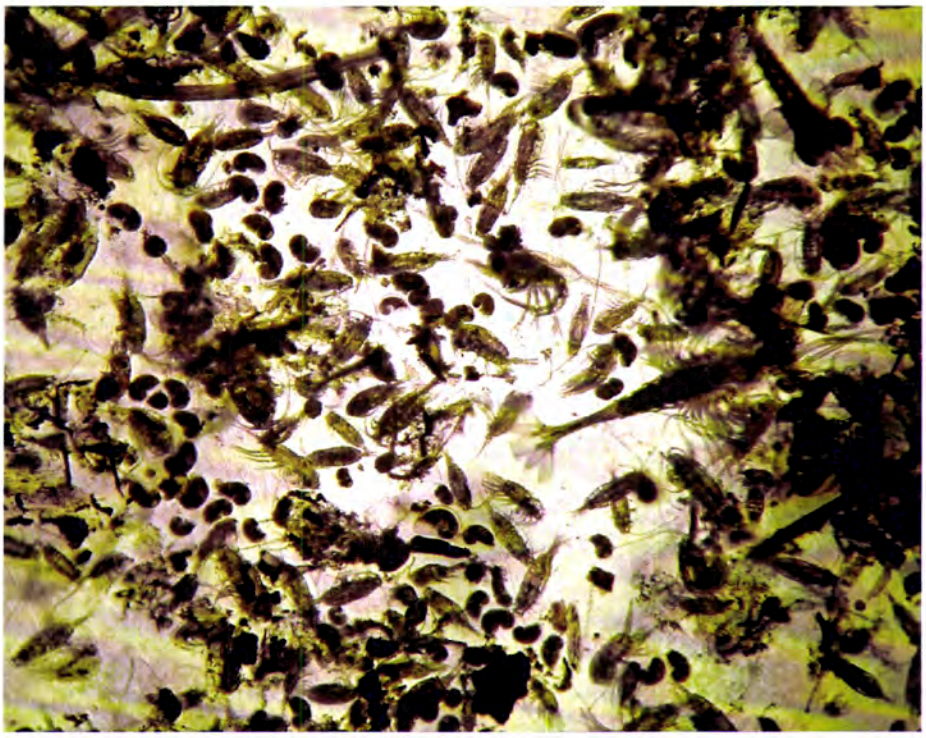

Plate. 1.1 An assorted sample of mesozooplankton

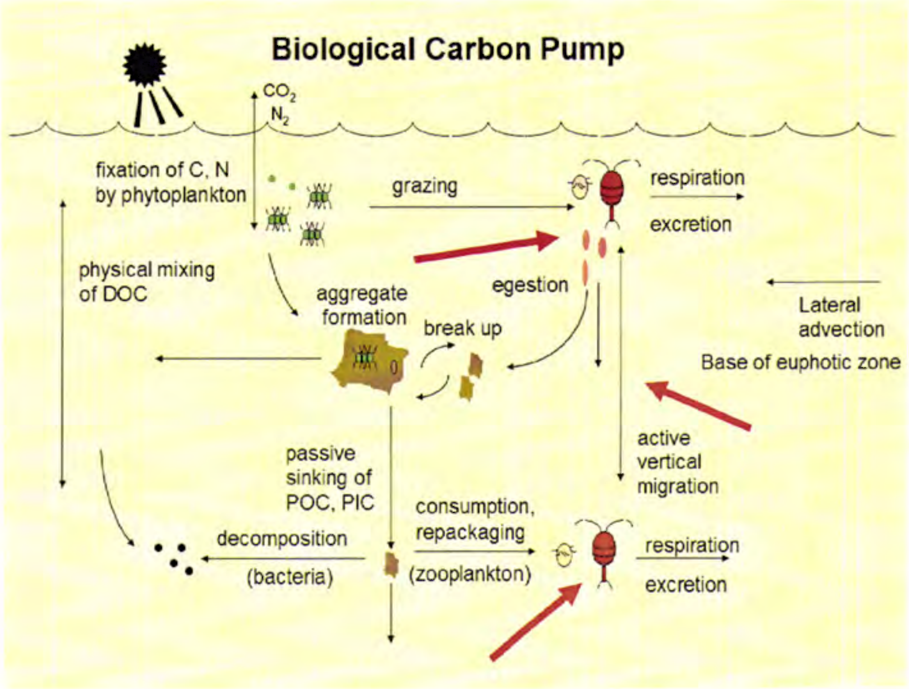

Plate. 1.2 Schematic diagram of the Biological Pump in the marine-ecosystem

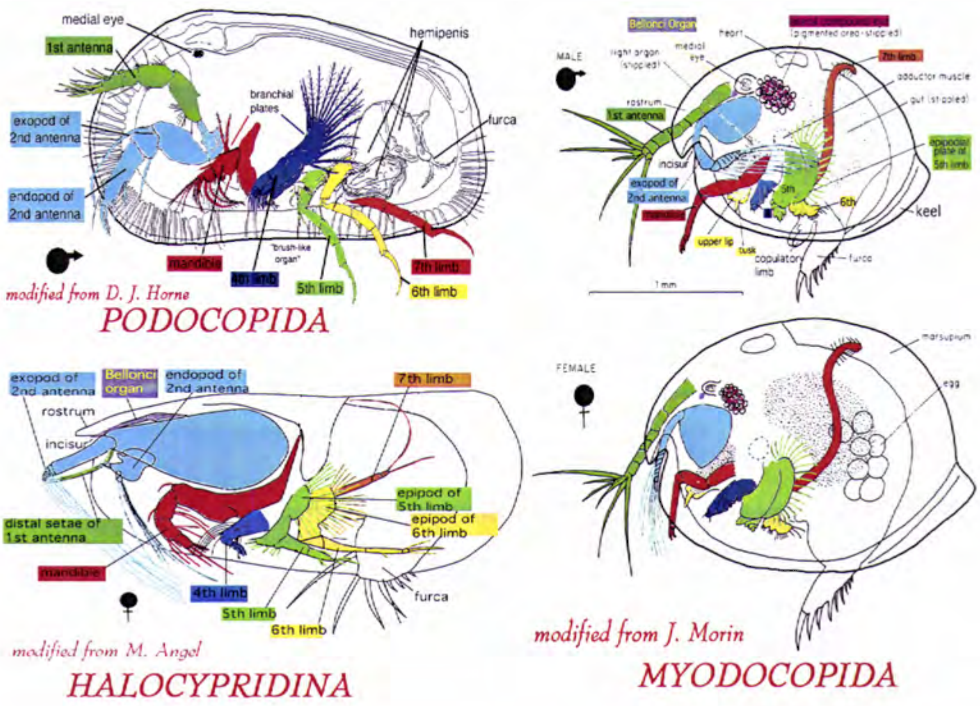

Plate. 1.3 Structural details of major ostracods Halocyprids, Myodocopids, Podocopids

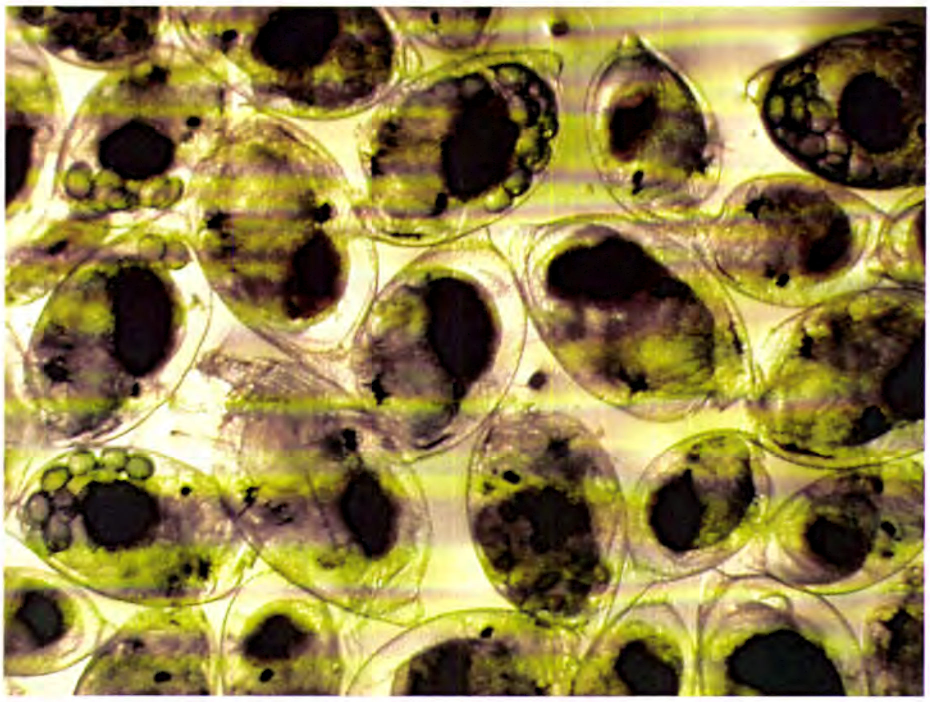

Plate. 1.4 Swarms of the ostracod *Cypridina dentata*

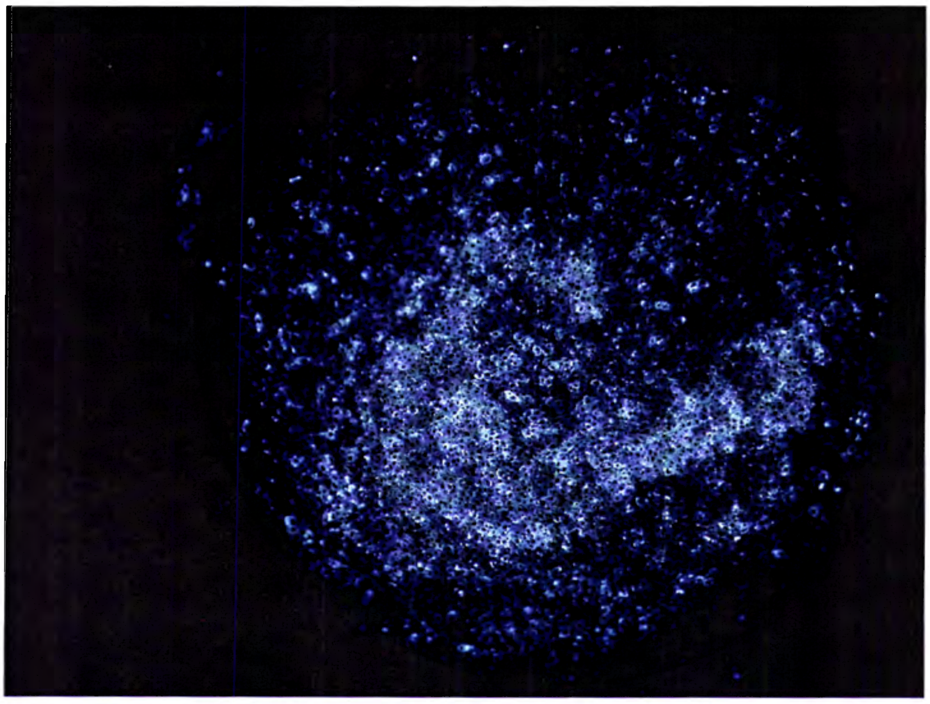

Plate. 1.5a

Plate. 1.5b

Plate. 1.5a &b Bioluminescence of the *Cypridina dentate*

* * *

Chapter - 2

MATERIALS AND METHODS

2.1 The Study Area

The study area is the Indian Exclusive Economic Zone (EEZ) divided between the Arabian Sea (AS) and the Bay of Bengal (BoB), in the northern Indian Ocean (Fig. 2.1). Both seas are situated in the same tropical basin, and are bordered to the north by Asian land mass, which has a marked influence on their hydrographic and biological characteristics. The basin experiences annually reversing monsoon currents, which are induced by the Southwest (SM) and Northeast (WM) monsoons. Between these monsoons are intermonsoonal transitions periods in spring (SIM) and in the Fall (FIM). There are marked differences between the physico-chemical properties of the AS and the BoB, which mainly arise from the impacts of the monsoon winds. A major influence on the BoB is the voluminous fresh water influx from the major rivers Irrawady, Brahmaputra, Ganges, Godavari, Krishna and Cauvery (Subramanian, 1993). In contrast, only two main rivers - the Tapti and Narmada discharge in to the AS. The freshwater inputs into the BoB, have been estimated to be 1.6×10^{12} m^3 yr^{-1} compared with inputs of just 0.3×10^{12} m^3 yr^{-1} into the AS (UNESCO, 1988). In addition, the negative water balance, resulting from the excess of evaporation over precipitation and the intrusion of Persian Gulf and the Red Sea generates warm and high saline water masses, modify the AS hydrography with high salinity water (ASHSW ca. 36). This leads to convective mixing and brings nutrients to photic zone, which support high biological production. In the BoB, the opposite is seen, i.e., there is a positive water balance, precipitation being in excess over evaporation (>2 m) and high riverine influxes, which lower surface salinities to ca. 33 and strongly stratified the upper ocean (Gill, 1982; Prasannakumar et al., 2002). This intense thermohaline stratification enhances the vertical stability in the upper water column and supresses convective mixing and entrainment of nutrients in to the photic zone. Therefore, the biological production is strongly nutrient limited and oligotrophic conditions are maintained.

During summer monsoon, the strong and steady southwesterly wind (Findlater, 1969) blowing over the northern Indian Ocean cools the surface waters and deepens the MLD in the open ocean. On the northern side of the Findlater jet upward Ekman pumping is induced, which advects the upwelled waters from the Arabian coast offshore, which makes the northern AS highly productive (Prasannakumar et al, 2001). In sharp contrast, in the northern BoB, the large riverine discharge creates a low saline cap, enhancing the thermohaline stratification and creating a thick barrier to the upward supply of nutrients (Pankajakshan et al., 2007a). However, along the west margin of BoB, wind induced Ekman transport pushes the surface waters offshore, so that they are replaced by cool and nutrient-rich subsurface water. Thus, the freshwater influx creates a shallow MLD along the east coast (Shetye et al., 1990). The West Indian Coastal Current (WICC) flows southward along the west coast of India, to merge with the Summer Monsoon Current (SMC) and intrude into BoB (Shankar et al., 2002). Similarly, the East Indian Coastal Current (EICC) flows northward along the east coast of India to 15°N, where it encounters a southward moving plume of fresher water and moves offshore (Muraleedharan et al, 2007). During FIM, the environmental conditions remain similar to those of summer monsoon, but with weak intensities. During this season, the maximum number of depressions and cyclonic storms are reported in the BoB. During the NEM, dry cool continental air (Northeasterly) from Tibetan plateau flows over both seas imparting momentum and heat flux and cools the ocean and causes evaporation making the surface waters high saline and dense (ASHSW), and these sink to deeper depths by buoyancy. As a result, nutrient rich subsurface water reaches to the surface layer, creating eutrophic conditions in the northern AS. However, these winds are not strong enough to erode the thick barrier layer in the BoB. Thus, NEM winds cool only the surface layer and the subsurface layer remains warm resulting in thermal inversion. During this period, EICC flowing southward, carrying low salinity BoB waters merges with Winter Monsoon Current (WMC) and enters the Arabian Sea (Prasannakumar et al., 2004). Mesoscale eddies are prominent features during the NEM north of 15°N. During the primary heating period, i.e. Spring inter Monsoon (SIM), the low saline waters flowing from the BoB is warmed in the south eastern AS (Burkill, 1999), and this induces stratification and development of a barrier layer that leads to the formation of the Arabian Sea Mini Warm Pool. Stratification in the BoB is intensified during this period by the presence of a deep isothermal layer. Most of the oceanic regions of the AS and BoB remain warm, stratified, and nutrients depleted.

The biological properties of the two seas are very much influenced by the atmospheric forcing, mixed layer processes and thermohaline stratification. The differential response of atmospheric forcing in the AS and the BoB is clearly evident in the secondary productivity characteristics.

2.2 Data source and Sampling Stations

2.2.1 Source of Data:

The present study was conducted under the umbrella project "Marine Research – Living Resources (MR- LR)" funded by the Ministry of Earth Sciences (MoES), Govt. of India. It was a multi-disciplinary programme covering the entire Indian EEZ, for measuring the environmental parameters along with the marine living resources (primary and secondary standing stock) up to a depth of 1000 m.

2.2.2 Seasons and Sampling Stations

The oceanographic cruises were conducted in the AS and the BoB, during different seasons and the samples were collected onboard FORV *Sagar Sampada* (Plate 2.1). The cruises were scheduled during Spring Inter monsoon (SIM; March May); Summer Monsoon (SM; June-September); Fall Inter monsoon (FIM; October); and Winter Monsoon (WM; November February) respectively (Table 2.1). The classification of seasons was based on the JGOFS programme for the AS and BoBPS programme for the BoB (Madhupratap et al., 2003).

Sampling was carried out on four cruises at one degree intervals along seven latitudinal transects in AS viz. 8°N, 10°N, 13°N, 15°N, 17°N, 19°N and 21°N and 6 latitudinal transects in BoB viz., 11°N, 13°N, 15°N, 17°N, 19°N and 20.5°N (Fig. 2.1). The total number of stations sampled was 47 in the AS and 35 in the BoB. Along each transect, the stations < 200 m depth were designated as 'coastal' and >200 m were designated as 'oceanic' Diurnal migration of mesozooplankton was studied at 2 stations along each transect.

2.3 Sample Collection and Processing

2.3.1 Physico-chemical parameters

A SBE Seabird 911 plus CTD (Plate 2.3) was used to record profiles of temperature (accuracy ± 0.001°C) and salinity (conductivity ± 0.0001 S/m) to depths of 1000 m (with bin sizes of 1 m). Salinity measured by CTD was calibrated against values observed for water samples collected from corresponding depths and measured using the Autosal (Guildline 8400A) onboard. The sea surface temperature (SST) was monitored using a bucket thermometer (accuracy of ± 0.2°C). Surface meteorological parameters (SST and wind) were collected continuously along the ship's track using a shipborne automated weather station. The mixed layer depth (MLD) was determined from the density profiles, as the depth at which density difference from the surface was 0.2 kg m^{-3} (Shetye et al., 1996). Thermocline depth was taken as depth at which water temperature decreased most rapidly.

Water samples were collected using a Rosette sampler connected to the CTD from standard depths (surface, 10, 20, 30, 50, 75, 100, 150, 200, 300, 500, 750, 1000 m) and used for measuring both physicochemical (Salinity, Dissolved Oxygen, Nutrients) and biological (Phytoplankton composition) parameters.

2.3.1.1. Dissolved Oxygen (DO)

DO was estimated by Winkler's method (Carpenter, 1965). Water samples from the standard depths were carefully collected in glass bottles without trapping air bubbles. Samples were immediately fixed by adding 0.5 ml of Winkler A (Manganous chloride) and 0.5 ml of Winkler B (Alkaline Potassium iodide) solutions and mixed well for precipitation. After acidification by 50% hydrochloric acid, samples were titrated against standard sodium thiosulphate using starch as indicator. The titration was based on iodimetry using a Dosimat. The endpoint was taken as the disappearance of the blue colour.

The Dissolved oxygen per liter of sample was calculated by

DO (ml/ litre) = $5.6\times N(S-b_m)\times V/(v-1)\times 1000/A$

Where,

N = Normality of the thiosulphate

S = Titre value for sample

b_m = Mean titre value for blank

V = Volume of the sampling bottle

A = Volume of sample titrated (50ml)

(v/v-1) was used to correct for the volume of reagents (1ml) added to125ml of the sample.

2.3.1.2. Nutrients

Water samples collected from standard depths were analyzed for nitrate, phosphate and silicate with a Segmented Flow Auto-analyzer SKALAR (Model 51001-1) immediately on board.

Nitrate (NO_3 - N): in the sample was first reduced to nitrite using a reactor column filled with amalgamated cadmium granules and the nitrite (NO_2) was allowed to react with sulphanilamide in acid medium (Grasshoff, 1983). The resulting diazonium compound was coupled with N-(1-Naphthyl) ethylene diamine dichloride to form a coloured azodye; the absorbance of which was measured spectrophotometrically at 543 nm. The concentration of reactive nitrate is expressed in $\mu mol\ l^{-1}$

Silicate (SiO_4 - Si): in the sample was acidified and mixed with an ammonium molybdate solution forming molybdosilicic acid. This acid was reduced with ascorbic acid to molybdenum blue, the absorbance of which was measured spectrophotometrically at 810 nm.

(PO_4 - P): Dissolved inorganic reactive phosphate was estimated by treating the sample with ammonium molybdate and potassium antimony tartarate in acid medium, when antimony – phospho molybdate complex was formed. This complex was reduced to intense molybdenum blue complex by ascorbic acid, which was measured spectrophotometrically at 880 nm.

2.3.2 Biological Parameters

2.3.2.1. Chlorophyll *a* and Primary productivity

Chlorophyll *a* and primary productivity were measured at the coastal and open ocean stations along each transect. Water samples were collected from seven discrete depths (0, 10, 20,50,75,100,120 m) according to the JGOFS protocols (UNESCO, 1994) and measured for primary productivity using the ^{14}C - technique (Steeman Nielsen,1952). Samples collected before sunrise were incubated *in situ* for 12 h after adding 1 ml of $Na_2H^{14}CO_3$ (5 μCi per 300 ml seawater). After the incubation, the samples were filtered through 47 mm GF/F (pore size 0.7 μm) filtered under gentle suction, exposed to concentrated HCl fumes to remove excess inorganic carbon and then stored in scintillation vials. Scintillation cocktail was added to the vials one day before the analysis, and the activity was counted using a liquid scintillation counter (Wallace, 1409 Finland). The Disintegrations per Minute (DPMs) were converted into daily production rates (mg C m^{-3} day^{-1}) using the formula of Strickland and Parsons (1972).

Primary production (mg cm^{-3} day^{-1}) = 1.05 x S_{DPM} x W/ S_A x T
Sample Activity (SA) = V* T_{DPM} / A_{vol}
Where,
1.05 – Correction for the lower uptake of ^{14}C compared to ^{12}C
S_{DPM} – DPMs in filtered sample
DPM – Disintegration per minute
V = Volume of filtered sample (litres)
A_{vol} = Volume taken to measure sample activity
T = Time (days)
W – Dissolved organic carbon (DIC) concenteration in sample (~25000 mg Cm^{-3})

The depth wise production was integrated to obtain the production for the entire euphotic zone.

Column production (mg C $m^{-2}day^{-1}$)

$= [(d_1-d_0)\ (a_0+a_1)/2 + (d_2-d_1)\ (a_1+a_2)/2 + \ldots\ldots\ldots]$

Where, d_0, d_1, d_2 are the depths sampled; a_0, a_1, a_2 are the respective production rates.

For **chlorophyll *a***, two liters of water from each depth were filtered through GF/F filters (pore size 0.7 µm), with the addition of one or two drops of magnesium carbonate solution and was kept in a refrigerator (Strickland and Parsons, 1972). The filter was extracted with 10 ml of 90% acetone and analyzed spectrophotometrically (Perkin- Elmer UV/Vis) at wavelengths of 750, 664, 647 & 630 nm. Total column chlorophyll *a* (mg m^{-2}) and primary production (mg C m^{-2} day^{-1}) were calculated by integrating the values across all depths.

The amount of the plant pigment in the original seawater sample was calculated using the equation (SCOR/UNESCO).

Chlorophyll a = 11.85 E 665 - 1.54 E 645 - 0.08 E 630
mg Chlorophyll/m^3 = C/V x 10
Where,
C = value obtained from the formula given above
V = volume of water filtered in litres
10 = volume of 90% acetone

2.3.2.2 Mesozooplankton

Mesozooplankton was collected at all stations from the upper 1000 m with a HYDROBIOS Multiple Plankton Net (MPN) of 0.25 m^2 mouth area and mesh size 200 µm (Plate 2.2). The MPN consists of a deck command unit and a stainless steel frame with canvas part to which, five net bags are attached by zip fasteners. The multi plankton sampler is operated with a remote command unit and underwater unit. The net bags are opened and closed sequentially by a succession of levers that are triggered by a motor unit. An integrated depth motor allows continuous supervision of the actual operating depth, which is indicated at the display of the deck command unit.

The underwater unit with all the net bags closed is lowered to the desired maximum depth. The first net bag is opened by a push button control from the deck. A signal from the motor unit to the deck command unit identifies the number of each net as it becomes operational. In each collection, the deepest stratum was sampled first, followed sequentially by the shallower strata, as the net was hauled vertically back up towards the surface at a speed of $1ms^{-1}$ Closing one net and opening the next using the push button control of the deck command unit at the upper limit of each sampling horizon.

The targeted horizons were 1000-500, 500-300, 300-BT (Bottom of Themocline Depth), BT – TT (Top of Thermocline depth), TT-surface (i.e. throughout the MLD). Prior to the estimation of the sample biomass, the larger zooplankters such as medusae, ctenophores, salps, siphonophores and fish larvae were picked out of the sample and their biomass were assessed separately and added to the rest of the zooplankton biomass if required. The samples from each depth horizon were sieved through 200 µm mesh, and any excess water was removed by absorbent paper, before the displacement volume was estimated (Harris et al., 2000). The formula used for the biomass calculation is as follows:

Biomass = DV / VWF

VWF = DH ×A

Where,

DV = displacement volume
VWF = volume of water filtered
DH = Difference in depth of haul
A= Mouth area of the net (0.25 m^2)

The mesozooplankton samples were immediately preserved in 4% buffered formalin (Steedman, 1979; ICES 2000). On return to shore, zooplankton abundances were estimated by counting all the individuals present in the sample or in aliquots depending on the biovolume. Samples having a displacement volume greater than 5 ml were subdivided, using either a Folsom splitter or a stempel pipette. The zooplankton biomass was estimated as $ml.m^{-3}$ (Wiebe et al., 1975; Smith, 1982; Wiebe, 1988; Banse, 1991; Kidwai &Amjad 2000a, b). The zooplankton was sorted into the major taxonomic groups and abundances were estimated as numbers per cubic meter. The ostracods (enumerated from aliquots) were counted from subsamples of each tow using a dissecting microscope (OLYMPUS BH-2). Ostracods were identified to species or genus level using the following works (Skogsberg, 1920; Poulsen, 1969, 1973; Angel, 1969a, b, 1971, 1999; George, 1971, 1977, 1979). The counts were converted to density (ind. m^{-3}) using the volume of water filtered by each net.

The abundance and relative abundance of each group was calculated using the formula, Abundance = No. of organisms of the particular taxon / VWF

= No. of a particular taxon in the unit volume (no./m^{-3})

Relative abundance = No. of specimens in the particular taxa / Total no. of organisms * 100

=Percentage of particular taxa (%)

2.3.2.3 Diel Vertical Migration of Mesozooplankton

Zooplankton samples were collected during day and night to document diel vertical migration at a coastal (200 m depth) and an oceanic (>1000 m depth) along each transect in both the AS and the BoB. At each DVM station, four series of samples were collected using the Multiple Plankton Net at 00:00, 06:00, 12:00 and 18:00 h local time from five depth strata during each of the four seasons. The night: day (N: D) ratio was calculated from the averages of night (02:00 and 21:00 h) and day (08:00 and 15:00 h) samples based on the local times of sunrise (06:05 h) and sunset (18:00 h) during the cruise. Diel migrant mesozooplankton biomass was estimated from the difference between night and day biomass in the euphotic zone (Dam *et al.,* 1995a).

2.4 Statistical Analysis

2.3.1 Analysis of Variance (ANOVA)

Three way ANOVA was used to compare between seasons, stations, between day and night and also to see whether there was any season – stations, season - day and night and stations – day and night, interaction based on the biomass of mesozooplankton and total species abundance of ostracods separately for each season (Snedecor and Cochran, 1967). Two way nested ANOVA was applied to compare the behavior of ostracod community in the AS and BoB. It is used in the case of unequal number of samples to be compared. This ANOVA has no exact test of significance for groups, it is required to check whether the given data satisfied the Gaylor and Hopper conditions (Gaylor and Hopper, 1969) based on which the Satterthwaites approximation is to be used. First it is verified whether degrees of freedom of sub groups is less than 100 and secondly whether the degrees of freedom of sub groups is less than twice the degrees of freedom of within groups. If these conditions are satisfied then it is tested either the ratio R is greater than C (Sokal and Rolf, 1981) and then Satterthwaites approximation is applied. In this nested 2 way ANOVA subordinate classification was nested within the higher level of classification. In particular, it is called a mixed model nested ANOVA (Sokal and Rholf, 1981).

2.3.2 Community Structure

The measurement of the temporal variation of diversity provided useful information in the succession of the community structure. Biodiversity was studied by defining the community structure in terms of five diversity indices calculated for each of these samples. Diversity indices such as Margalef's index for species richness (Margalef, 1968), Simpson index for species concentration (Simpson (1949),Shannon Weaver diversity index for species diversity (Shannon and Weaver, 1963), Heip's index for evenness or species equitability distribution (Heip, 1974) and Pielou's index for dominance were computed separately for ostracods. Indices used for the calculation are given below.

1. **Margalef's (1957) richness index** is defined as

$$d = (S-1) \div \ln N$$

where S is the total number of species in a sample, d is richness measurement and N is the total number of individuals of all the species in a sample.

2. **Shannon – Weaver** (1963) **diversity index** is:

$$H(S) = -\sum_{i=1}^{i=s} [\, p_i \log_2(p_i) \,]$$

where $p_i = (n_i/N)$, n_i is the number of individuals of the i^{th} species, N is the total number of individuals of all species, and S is the total number of species observed. The importance of this diversity index is that it has a probability distribution and hence can be used for comparison of stations using critical ratio tests unlike other diversity indices.

3. **Evenness index** given by **Heip's** (1974) formula is:

$$\varepsilon = [EXP[H(s)] - 1]$$

where $e^{H(S)}$ is the equivalent number of equally distributed species. Equitability is defined as the ratio of the number of species observed to the number of species that are theoretically required by MacArthur's model to achieve the same diversity with equitable (or even) distribution of individuals among the species in a population (Lioyd and Ghelardi, 1964). Log normal distribution is fitted for both diversity and evenness indices (Snedecor and Cochran, 1967).

4. **Pielou's (Pielou, 1971) index of species dominance** given by

$$D = H(S)/H(S)_{max}$$

Where D is dominance value, $H(S)$ is Shannon-Wiener diversity index and $H(S)_{max}$ is the maximum value of $H(S)$ in a sample

5. Simpson's (Simpson, 1949) index given by the formula:

$$Sp = \sum_{i=1}^{i=s} [n_i(n_i - 1)]/[N(N-1)]$$

where N is the total number of individuals in the sample, S is the number of species and n_i is the number of individuals of the i^{th} species

2.3.3 *Similarity Index*

The similarity between species and stations during different seasons were studied using the Bray/Curtis similarity index (Clifford and Stephenson, 1975). In this, the standardized values of fourth root transformed data of abundance of species were used to see the species clustering/ specificity at different seasons and stations/ depths. Similarity index calculated for species presented as a dendrogram using group linkage clustering techniques. Similarity between stations were carried out as (Clarks & Gorley, 2001) nonmetric, Multi Dimensional Scaling (nMDS) using Plymouth Routine in Marine Environmental Research (PRIMER, V5, Clarke and Gorley, 2001).

Table 2.1 Details pertaining to the cruises conducted in the AS and BoB

Research Vessel	FORV Sagar Sampada	
Study Region	Season	
Arabian Sea (8 -21°N; 66-75°E)	Spring Inter monsoon Summer monsoon Fall Intermonsoon Winter monsoon	(SIM) (SM) (FIM) (WM)
Bay of Bengal (10-20°N; 80 -86 °E)	Spring Inter Monsoon Southwest Monsoon Winter monsoon	(SIM) (SM) (WM)

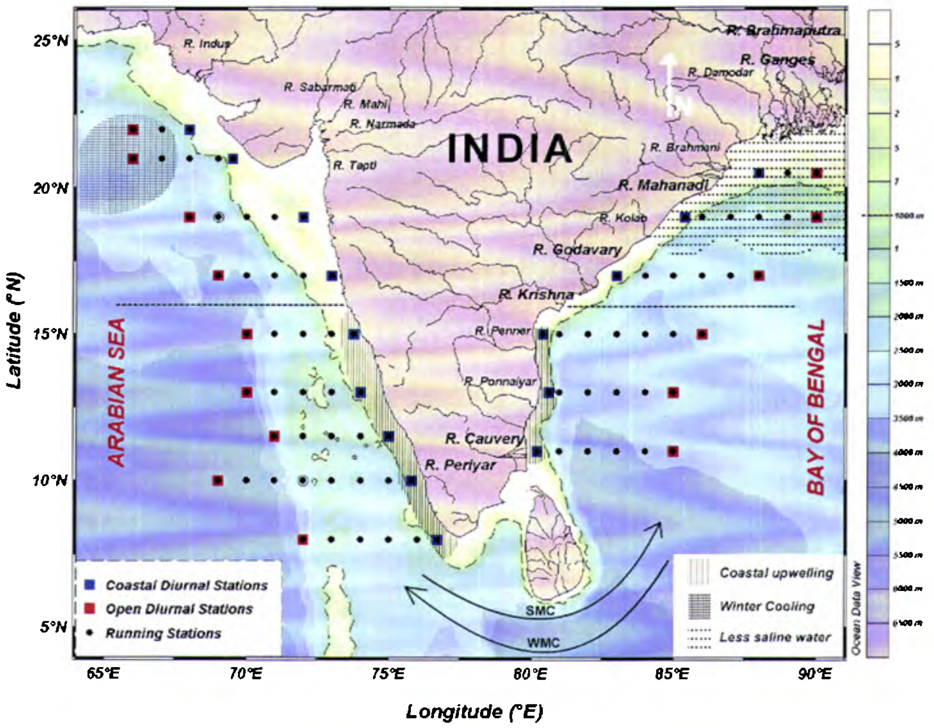

Fig. 2.1 Station locations in the Arabian Sea and the Bay of Bay of Bengal (•) indicating the open ocean diurnal stations and (■) indicating the coastal diurnal stations.

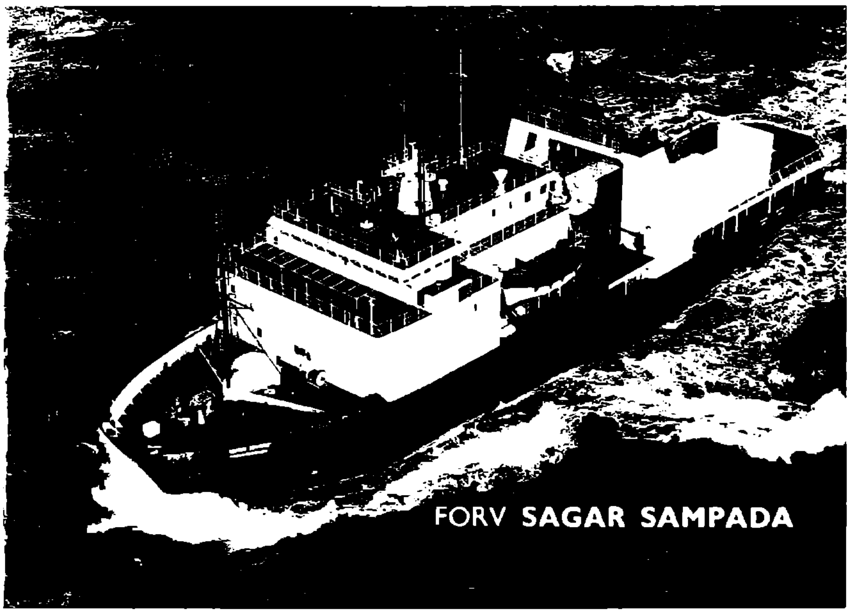

Plate 2.1 The Research vessel FORV Sagar Sampada

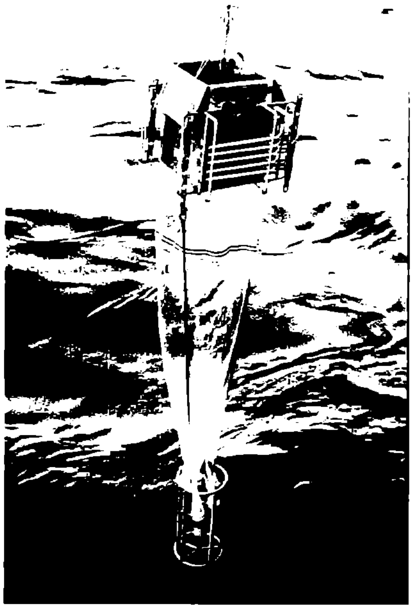

Plate 2.2 Multiple Plankton Net (MPN)

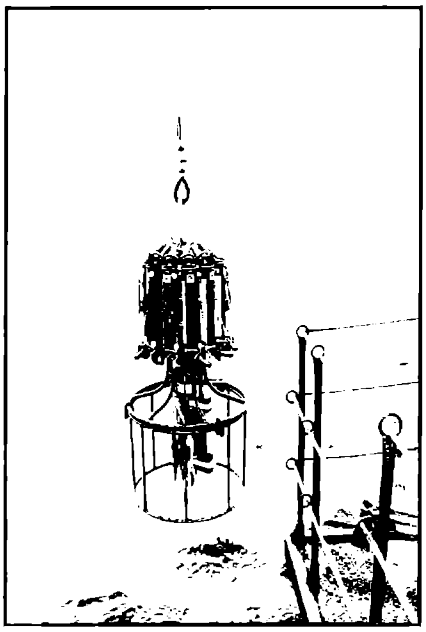

Plate 2.3 Conductivity Temperature Depth (CTD)

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Chapter - 3

MESOZOOPLANKTON OF THE ARABIAN SEA

The biological characteristics of the Arabian Sea are found to be closely linked with the seasonally reversing monsoons and associated circulation patterns. The surface meteorological features and vertical profiles of temperature, salinity, density, nutrient and dissolved oxygen were clearly indicating the response of seasonal variation on the biological productivity of the AS. This chapter focuses on the seasonal and vertical distribution of mesozooplankton biomass during various seasons in the eastern AS.

3.1 Hydrography of the Arabian Sea

Spring intermonsoon (April-May)

During SIM, the winds prevailing over the northeast AS were northwesterly with an average speed of 5 m/s; while relatively weak winds (< 2 m/s) were observed southeastern AS (Fig. 3.1a). Sea surface temperature showed a decreasing trend from south (30°C) to north (28.5°C), while surface salinity and density showed an increasing trend (Fig. 3.2a) from south (34.5 and 21kg/m^3) to north (35.5 and 23.5 kg/m^3). Shallow MLD (<40 m) was noticed along the coastal stations that deepened to ~60 m at oceanic stations (Fig. 3.3& 3.8a). Deep thermocline (300 m) observed along the oceanic stations of northern latitude gradually decreased to 200 m towards the southern transect (Fig. 3.4&3.8b). The distribution of DO was unique (~200 µM) in the eastern AS during this season with a slight increase from south to north. Nutrients (NO_3, PO_4 and SiO_4), were high (> 0.2 µM, > 0.4 µM, > 1.5 µM respectively) in the surface layers (Fig. 3.5).

Warm (30°C) and thick isothermal layer (75 m) was observed in the South Eastern Arabian Sea (SEAS) where the salinity (< 34) and density (21.5 kg/m^3) was low (Fig. 3.4a) compared to North Eastern Arabian Sea (NEAS). The core of the ASHSW could be seen in the surface 150 m layer along the northern coastal region, the thickness of which gradually decreased towards south (10°N) to a depth of 80 to 100 m depth. In the oceanic section, ASHSW water mass can be identified up to 8°N at a depth range of 60 to 120 m. Density structure was in agreement with the flow pattern and thickness of ASHSW The surface and subsurface layers were stable in the SEAS, while NEAS showed stability in the surface layer only. DO and nutrients (DO >200 µM, nitrate >0.5 µM, phosphate > 1 µM and silicate > 3 µM) in the coastal (Fig. 3.6) and oceanic waters (Fig. 3.7) supported moderate primary production in the warm mixed layer. The oxygen minimum layer (OMZ, DO < 20 µM) was found extended up to 10°N at a depth range of 300 to 500 m from the northern AS, while intense oxygen minimum (10µM) was noticed (Fig. 3.7) at depths of 500 to 750 m in the northern AS.

Summer monsoon (June-September)

During the summer monsoon, winds were predominantly southwesterly with occasional north westerlies near the southern coast (8° to 15°N). Strong winds (~12 m/s) prevailed off northern and southern transects, while relatively weak winds (< 5m/s) were observed along southern coastal stations and southern most transect (Fig. 3.1b).The most significant feature of the AS was the observed cooling (< 26.5°C) along the southwest coast of India and northern AS (Fig. 3.2b). SST along the southern coastal stations was almost

2.7°C lower than that in the open ocean. Intense cooling was noticed along the coastal station of 10°N (~26.1°C), which was about 3.4°C cooler than the open ocean waters. Northern stations also showed cooling (1°C cooler at 15°N transect), but the cooling was lower compared to the southern coastal stations. Maximum SST was observed at 15°N transect which extended to oceanic stations of 10° and 13°N. The SSS of coastal waters varied from 34.5 (southern) to 36.8 (northern) while (Fig. 3.2b) oceanic regions did not exhibit any variation. Subsurface salinity near the coast along 8° and 10°N was about 0.6 higher than the oceanic station, indicative of the coastal upwelling, where the cool high saline waters replaced the warm, low saline waters. A cap of low saline waters seen in the surface of the coastal region of the southern transect may be due to the freshwater influx (riverine and high precipitation). This low saline water formed as a lens at the surface of SEAS. MLD varied between 10 (coastal) and 80 m (oceanic) and the lowest value was observed near the coast along 10°N (Fig. 3.3b). Shallow MLD was noticed along the coastal stations that gradually deepened towards the oceanic regions (Fig. 3.4b). The stable surface layer was observed along the coastal stations, while the stable layer in the oceanic stations was seen below the MLD. The DO remained same (~200 µM) in the oceanic stations compared to the coastal stations. A slight decrease in the DO was noticed at southeastern coast (190 µM) and oceanic region along 17°N (180 µM). Nutrients (NO_3, PO_4 and SiO_4) were present in surplus (> 0.2 µM, > 0.4 µM, > 1.5 µM respectively) especially in the surface layers (Fig 3.5b), where nitracline varied from 10 to 80. In the oceanic stations, nitracline was below 50 m, but shoaled to the surface at 8°N and 10°N coastal stations (Fig. 3.6b). Phosphate and silicate were also present in surplus in the surface.

Thermal structure along the coast showed an upheaving of isotherms at 10°N indicating the movement of cool subsurface waters to the surface. The core of ASHSW seen at a depth of 50 m was progressively diluted towards south. The thermohaline and isopycnals also showed (Fig. 3.4b) the same trend towards the southern stations. Properties of oceanic, subsurface (~70 m) waters were identified at coastal stations. Relatively high saline surface waters (>35.2) were seen along near shore and low saline waters (<34.8) along offshore. It could be seen that denser waters from 60 m reached the surface near the coast. There were indications of down welling below a depth of about 100 m in the temperature and density profiles (Fig. 3.4b). In the coastal waters, vertical sections of DO and nutrients (Fig. 3.6b) showed up slopping at 10°N (DO <180 µM, nitrate >2.0 µM, phosphate > 1 µM and silicate > 4 µM). 20 µM contour of oxygen was extended up to 10°N offshore at a depth of 300- 500 m in the northern AS, while intense oxygen minimum zone (10µM) extended up to 11° 30' N at 500 -750 m depth.

Fall intermonsoon (September - October)

During FIM, surface winds were variable and predominantly southwesterly-westerly along oceanic region and north westerly along the southern coastal region (Fig. 3.1c). Strong westerlies (8 m/s) at northern oceanic stations and weak westerlies (<3 m/s) at oceanic stations of 8°N, 10°N and 13°N were noticed. Movement of sun from the northern hemisphere initiates the secondary heating period (Intermonsoon Fall), the oceanic regions showed maximum sea surface temperature (29°C) compared to the coastal waters (28.5°C). Lowest SST (27°C) was noticed at the coastal station of 15°N (Fig. 3.2c). SST near the coast along 8° and 10°N were almost 1°C lower than the open ocean waters. SSS ranged between 33.9 to 36.8 and the low saline waters following monsoon run off was spread along the entire west coast. Sea surface salinity showed an open to coastal gradient ranging from 36.5 to 35.0 (Fig. 3.2b). The density closely followed salinity in the entire study region with a range 22 23.5 kg.m^{-3} (Fig. 3.2c). MLD increased from the coastal (10 m) to oceanic stations (80 m), whereas thermocline deepened towards north (100 to 300 m). The coastal waters showed greater stability in the south (10 cycles/hr) compared to the north (-10 cycles/hr). The hydrographic conditions were fairly steady and the region behaved oligotrophic. However, in the coastal waters of 10°N dissolved oxygen (195 µM) and nitrate (> 2 µM) were moderate and silicate was low (Fig. 3.5c).

The distribution of salinity showed the presence of ASHSW as a protrusion towards the coast of 10°N at a depth of 20 to 40 m. There were indications of down welling below 100 m in the temperature and density sections (Fig. 3.3c). Vertical section of temperature, salinity and density along the oceanic stations also showed an upward lift towards the southern stations (Fig. 3.4c). Coastal sections (Fig. 3.6c) recorded low DO (185µM), high nitrate (>2.5µM), phosphate (0.6µM and silicate (2.5µM) at 15°N. In the oceanic section(Fig. 3.7c), distribution of DO and nutrients in the MLD were uniform, while intense oxygen minimum zone (10µM) was seen from the 15°N to 19°N stations at depth of 300 to 750 m.

Winter monsoon (November – February)

During the winter monsoon, northeasterly winds (7 m/s) prevailed over the oceanic regions of AS, but winds were weak (1 m/s) in the SEAS (Fig. 3.1d). SST gradually increased from north (26°C) to south (29°C) (Fig. 3.2d). The sea surface salinity decreased from oceanic (36.5) to coastal (32.5) waters (Fig. 3.2d). The lowest SSS was noticed at the 8°N; 74°E station. The density followed the salinity pattern from oceanic (24) to coastal (21.5 kg.m^{-3}) waters (Fig. 3.2d). MLD (40 m) along the coastal stations were shallow (Figs. 3.3d & 3.8d) which gradually deepened (60 m) towards the oceanic stations (Figs. 3.4d & 3.8d).Thermocline also showed an increasing trend from coastal (150 m) to oceanic stations (250 m). Stability was high stable in southern coastal and oceanic station, which decreased towards the north. Surface distribution of DO (195 µM) and nutrients (NO_3 0.4µM, PO_4 0.4 µM and SiO_4 0.4 µM) were almost consistent (Fig. 3.5d), but silicate (SiO_4 1µM) along 8°N transect was very high.

Thermohaline distribution along the coast showed a thick layer of warm (29°C) and low saline (<35.6) waters in the southern region, which tapered off towards the north. Below this layer traces of ASHSW can be seen (Fig. 3.4d). Density section followed temperature in the high saline waters and followed salinity in low saline waters. There was no variation in the oceanic thermohaline distribution in the surface layers, below which, spreading of ASHSW to the southern station (Fig. 3.4d) was evident. Along the coastal section, DO was saturated (Fig. 3.6d) in the northern stations (200µM) compared to the southern stations (190 µM). Oceanic section showed uniform DO at upper layers with intense (Fig. 3.7d) oxygen minimum (10µM) at15°N at 500 m. Nutrients (NO_3, PO_4 and SiO_4) along the coastal section remained low at south (0.4, 0.05 and 4µM) and increased towards north, but with a reversing trend for silicate. Along the oceanic section, nutrients were almost uniformly distributed.

3.2 Biological characteristics

3.2.1 Chlorophyll *a* and primary production

Spring intermonsoon

The surface chlorophyll *a* varied in the range of 0.03 to 0.51 mg m^{-3} (av. 0.22 mg m^{-3}). The corresponding column chlorophyll *a* varied from 4.62 to 38.8 mg m^{-2} (av.18.8 mg m^{-2}). The average coastal surface (column) chlorophyll *a* in the NEAS were 0.27 mg m^{-3} (24.07 mg m^{-2}) and the corresponding offshore values were 0.09 mg m^{-3} (9.11 mg m^{-2}) respectively (Table 3.1&3.5).

The eastern Arabian Sea was more or less oligotrophic and showed the lowest primary production during the spring inter monsoon. Extensive blooms of *Trichodesmium erythraeum* were observed off Goa and off Bombay during the study period. The surface production varied from 1.01 to 4.74 $mgCm^{-3}d^{-1}$ and the column production was 97.25 to 201.59 $mgCm^{-2}d^{-1}$ (avg.153 $mgCm^{-2}d^{-1}$).The average surface (column) values of coastal stations in SEAS were 4.74 $mgCm^{-3}d^{-1}$ (182.62 $mgCm^{-2}d^{-1}$) and the offshore values were 2.88 $mgCm^{-3}d^{-1}$ (129.15$mgCm^{-2}d^{-1}$) respectively (Table 3.1&3.5).

Summer monsoon

The surface chlorophyll *a* was in the range 0.12 to 1.98 mg m^{-3} (av. 0.50 mg m^{-3}). The corresponding column values varied from 8.9 to 68.9 mg m^{-2} (av. 26.74 mg m^{-2}). The average coastal surface (column) chlorophyll *a* were 0.77 mg m^{-3} (32.4 mg m^{-2}) and the off shore values were 0.24 mg m^{-3} (21.2 mg m^{-2}) respectively. The average surface (column) chlorophyll *a* in the north coastal stations were 0.23 mg m^{-3} (17.44 mg m^{-2}) and the offshore values were 0.21 mg m^{-3} (24.60 mg m^{-2}), respectively (Table 3.1&3.5)

The surface primary production varied from 1.4 to 121.9 $mgCm^{-3}d^{-1}$ (av. 16.8 mg C $m^{-3}d^{-1}$). The coastal stations off Kanyakumari, Kochi, and Calicut showed comparatively higher production (1313 $mgCm^{-2}d^{-1}$) during this season. The maximum surface primary production was recorded in the inshore station off

10° latitude (122 mg C $m^{-3}d^{-1}$), which is experiencing strong upwelling.

Fall intermonsoon

The Arabian Sea exhibited a wide range in chl *a* and primary productivity values. The average surface (column) chlorophyll *a* in the southern coastal region were 0.53 mg $Cm^{-3}d^{-1}$ and 33.85 $mgCm^{-2}d^{-1}$ and that for the northern region were 0.33 $mgCm^{-3}d^{-1}$ and 21.50 $mgCm^{-2}$ d^{-1} respectively (Table.3.1). The surface primary production varied from 2.01 to 10.67 $mgCm^{-3}d^{-1}$ (av. 6.3) in the open ocean stations and 4.17 to 37.43 mg $Cm^{-3}d^{-1}$ (av.11.8 $mgCm^{-3}d^{-1}$) in coastal stations. Integrated column production varied from 173.4 to 571.9 $mgCmg^{-2}d^{-1}$ (av. 306.5 $mgCm^{-2}$ d^{-1}) in the open ocean stations and from 179.1 to 1630.1 $mgCm^{-2}d^{-1}$ in the inshore stations (av. 495.7 $mgCm^{-2}d^{-1}$).

The average surface (column) primary production in the southern coastal region were 15.4 mg $Cm^{-3}d^{-1}$ and 691 $mgCm^{-2}d^{-1}$ and that for the northern region it was 7.21 $mgCm^{-3}d^{-1}$ and 175.73 $mgCm^{-2}$ d^{-1} respectively. At 10°N and 75°E an enhanced rate of column primary productivity of 1630 $mgCm^{-2}d^{-1}$ and 60.7 mgm^{-2} chl *a* was obtained. Thus, PP and chl *a* were generally high in the coastal stations than the oceanic waters (Table 3.1). In general, the southeastern Arabian Sea (8°N -15°N) was found to be more productive than the northeastern Arabian Sea (15°N-21°N) (Table 3.1).

Winter monsoon

The biological production in the AS generally varied between northwest and southwest coast. The integrated PP ranged from 141 to 1854 mg C m^{-2} d^{-1}, with an average of 375 mg C m^{-2} d^{-1} in the south west and 1396 mg C m^{-2} d^{-1} in the northwest coasts (Table 3.1).

Similarly, the column chlorophyll *a* ranged from 4.1 to 82.4 mg m^{-2}, with average values of 21.46 (southwest coast) and 58.77 mg m^{-2} (northwest coast). The maximum PP and chlorophyll *a* were recorded at 21°N: 69°E (open ocean waters off Veraval), which was about 7-8 folds higher than that of the measured values in south.

3.2.2 Vertical distribution of mesozooplankton

Spring intermonsoon

The average mesozooplankton biomass in the upper 1000 m was 0.59 $ml.m^{-3}$ and in the mixed layer, it was 0.40 $ml.m^{-3}$ (Fig. 3.8a & Table 3.2). During this season, the biomass was maximum in the mixed layer of northern regions viz., 15°N; 73.5°E (1.2 $ml.m^{-3}$) and 17°N; 71°E (1.4 $ml.m^{-3}$) and the lowest biomass of 0.3and 0.2 $ml.m^{-3}$ was in the southern stations of 8° and 13°N (Fig. 3.8a). In the thermocline layer the average mesozooplankton biomass was 0.16 $ml.m^{-3}$ and it uniformly distributed throughout the stations (Fig. 3.8a). Towards the deeper layers, (300-BT, 500-300, 1000-500) the mesozooplankton biomass decreased gradually from 0.04 to 0.01$ml.m^{-3}$ (Fig. 3.8a, 9a & 3.10a).

About 22 mesozooplankton taxa were identified during this season. The most abundant taxon was copepods (>80%) in both mixed layer and thermocline layer (Fig. 3.14 &Table 3.3). The second abundant group in the mixed layer was ostracods followed by chaetognaths with a percentage contribution of 7.96 and 4.61% respectively. The upper 1000 m water column also showed the same composition of mesozooplankton taxa in a decreasing order of Copepods > Ostracods > Chaetognaths > Salps > Decapods > Euphausiids etc. (Table 3.3)

Summer monsoon

The average mesozooplankton biomass in the upper 1000 m was 2.07ml.m^{-3} and in the mixed layer it was 1.47 ml.m^{-3} (Fig. 3.8b &Table 3.2). The highest biomass of 10.93 ml.m^{-3} was recorded in the mixed layer along the coastal station off Kochi (10°N; 75°E) (Fig. 3.1b). In the thermocline layer, the average mesozooplankton biomass was 0.34 ml.m^{-3} where the maximum biomass (1.13 ml.m^{-3}) was observed in the 17°N; 73°E and10°N; 75°E (Fig. 3.2b). Towards the deeper layers, i.e in the 300-BT, 500-300, 1000-500 the mesozooplankton biomass decreased gradually from 0.18 to 0.02ml.m^{-3} (Fig. 3.8b, 3.8b &3.10b).

As pointed out for the spring inter monsoon, copepods comprised the majority of the mesozooplankton taxa in almost all the stations during summer monsoon, but the contribution of copepod to the mesozooplankton taxa was drastically decreased to 59% in the mixed layer and 69% in the thermocline layer (Fig. 3.14b&Table 3.3). The other mesozooplankton groups that flourished during this season was ostracods (12.14% in the MLD) but their occurrence was high in the thermocline region (17%). Euphausiids (3.72%) and chaetognaths (3.5%) were abundant in both MLD and thermocline depth. Euphausiid swarm (10523 ind.m^{-3}) was observed in thermocline depth and Siphonophore was abundant (929 ind.m^{-3}) in the mixed layer of the coastal station off Kochi (10°N; 75°E). Shoals of sardine juveniles (approx. 5 – 7 cm) was also observed at the same station, where the mixed layer depth was very shallow. The highest abundance of fish eggs and larva was seen during summer monsoon with a percentage contribution of 0.70% and 0.18%. (Table 3.3). Salps and Jellyfishes dominated at almost all stations along Kochi (10°N) and Kanyakumari (8°N).

Fall intermonsoon

The average mesozooplankton biomass in the upper 1000 m was 0.62ml.m^{-3} and in the mixed layer, it was 0.44 ml.m^{-3} (Table.3.2). The highest biomass (1.38 ml.m^{-3}) was seen in the mixed layer along the coastal station of 10°N; 75°E (Fig. 3.8c). The open ocean stations of 15° and 13°N transects also recorded highest biomass in the mixed layer with a value of 1.17 and 1.08 ml.m^{-3}, respectively (Fig. 3.8c). In the thermocline region the maximum biomass (0.55 ml.m^{-3}) was observed at 8°N; 76.5°E (Fig. 3.8c).

In the mixed layer and the thermocline layer, copepods formed the dominant group of mesozooplankton with a contribution of 83.3 and 81.5 % respectively followed by ostracods (9.9 %) and chaetognaths (3.2 %) (Table 3.3).

Winter monsoon

The average mesozooplankton biomass in the upper 1000 m was 0.3 ml.m^{-3} and in the mixed layer was 0.18 ml.m^{-3} (Fig. 3.8d &Table 3.2). The maximum biomass (0.72 ml.m^{-3}) was seen in the mixed layer in the open ocean off 19°N; 69°E (Fig. 3.8d &Table 3.2) and 21°N; 69°E (0.4 ml.m-3).In the thermocline layer, the average mesozooplankton biomass (0.04 ml.m^{-3}) and the maximum biomass (0.22 ml.m^{-3}) was observed in the 21°N; 69°E (Fig. 3.8d). In the deeper depths 300-Bt, 500-300 and 1000-500, the mesozooplankton biomass decreased to 0.052 ml.m^{-3}, 0.048 ml.m^{-3} and 0.011 ml.m^{-3} respectively (Table 3.2). During this season northern transects (21° and 19°N) showed high biomass than the southern transects (13 and 10°N).

In the mixed layer and the thermocline layer, copepods formed the highest component contributing 71 % (7667 ind.m^{-3}) and 55%

(1272 ind.m^{-3}) respectively. Ostracod is the second dominant group with a contribution of 12.84 % (1380 ind.m^{-3}) in the MLD and 31% (723 ind.m^{-3}) in the thermocline layer (Fig. 3.14 &Table 3.3). The other taxa were Chaetognaths (8.31%), decapods (1.34%), Siphonophores (1.97%). Others (Amphipod, Doliolids, Cephalopod, Fish larva) averaged less than 1% of total abundance (Table 3.3).

3.2.3 Coastal and oceanic variabilityofmesozooplankton

Coastal distribution

Mesozooplankton standing stock was generallyhigh in the coastal regions during all seasons and all depth layers. In the mixed layer, mesozooplankton biomass was maximum during summer monsoon (mean 1.2±1.829 ml.m^{-3}). During winter monsoon, the biomass was low (0.212 ±0.079 ml.m^{-3}) compared to spring and fall inter monsoons (Table 3.4). The coastal regions of 8°N and 10°N latitudes showed the high biomass (5.4 &1.4 ml.m^{-3}) compared to the northern coastal regions (Fig. 3.13) during summer monsoon. Mesozooplankton biomass was almost uniform in the mixed layer during other seasons.

In the thermocline layer the highest mean biomass (0.37±0.41 ml.m^{-3}) was during summer monsoon (Table 3.4) and the lowest biomass during winter monsoon (0.05±0.04 ml.m^{-3}) than spring (0.25±0.20 ml.m^{-3}) and fall inter monsoons (0.18±0.17 ml.m^{-3}). At 8°N, the highest biomass of 0.9 ml.m^{-3} was recorded during the summer monsoon whereas during spring intermonsoon (0.6 ml.m^{-3}) and fall inter monsoon (0.5 ml.m^{-3}) it was at 19°N and 8°N (Fig. 3.13).

Maximum abundance of mesozooplankton taxa were identified during summer monsoon with an average of 2277 ind.m^{-3} in the mixed layer. Copepods always comprised the largest fraction both in the mixed layer and thermocline layer (Fig.3.8&3.9). Copepods dominance was maximum (88%) during fall intermonsoon (Fig. 3.14) and least during summer monsoon (45%). Ostracods contributed to about 13% in the mixed layer and 23% in the thermocline layer along the coastal regions during winter monsoon. A significant component of biomass during summer monsoon was also comprised of the larger carnivores such as Chaetognatha (3.97%), Siphonophora (5.9%) etc. A wide variation in the composition of mesozooplankton taxa was observed between the southern and northern coastal regions.

Copepod composition was highest in the northern (<85%) than in the southern coastal regions except during winter monsoon. (Fig. 3.14). During summer monsoon, the copepod biomass was drastically reduced to 42% in the southern coastal regions and was subsequently replaced by chaetognaths and siphonophores.

Oceanic distribution

Compared to the coastal region, mesozooplankton standing stock was reduced considerably in the oceanic regions during all seasons (Table 3.4). Highest mesozooplankton biomass was seen in the mixed layer during summer monsoon (mean 0.653±0.207ml.m^{-3}). The oceanic regions in the southern latitudes (8-15°N) showed higher biomass (1.2 – 1.8 ml.m^{-3}) than the northern regions (Table 3.5) during summer monsoon. During winter monsoon, (Table 3.5)the mesozooplankton biomass was high in the northern latitudes of 19°N and 20°N (0.7 ml.m^{-3}).

In the thermocline layer also the highest mean biomass (0.31±0.25ml.m^{-3}) was observed during summer monsoon (Table 3.4) followed by spring intermonsoon (0.11±0.12 ml.m^{-3}). Northern latitudes showed high biomass than southern latitudes during winter monsoon (Fig. 3.13).

Maximum abundance of mesozooplankton taxa were identified during summer monsoon (av.560 ind.m^{-3}) in the mixed layer. In oceanic regions also, copepods were the numerically abundant both in mixed layer and thermocline layers (Fig. 3.14). Their percentage contribution was maximum during spring (81%) and fall inter monsoons (75%). Ostracods were the second dominant group in the thermocline layer during winter monsoon (51%) and summer monsoon (21%).

Similar to the coastal stations, there was a considerable north - south variation in the composition of mesozooplankton taxa in the oceanic region. During winter monsoon, ostracods constituted 42% of the biomass in the northern oceanic stations (Fig. 3.14). The relative composition of different taxa between the spring and fall inter monsoons were not apparent in the northern oceanic regions.

3.3 Statistical Analysis

Analysis of Variance (ANOVA)

3 way ANOVA was applied for comparing the mesozooplankton biomass, between seasons, between stations in different latitudes, and between day and night in the different depth layers of the coastal and oceanic regions in the Arabian Sea (Table 3.6a & 3.6b). Mesozooplankton biomass varied widely between seasons more significantly than between latitudes in the coastal stations, as evident from the F- ratio (Table 3.6a). Biomass in the mixed layer of the coastal stations varied between seasons ($F_{(3, 18)} = 11.6598$, $P < 0.01$) and also with respect to stations ($F_{(6, 18)} = 6.5766$, $P<0.01$). Mesozooplankton biomass in the coastal stations showed significant difference in both mixed layer ($P <0.01$) and thermocline layer ($P < 0.01$) between seasons. Both Latitudinal

difference and latitude - seasonal interaction of the mesozooplankton biomass was significant in the mixed layer $F_{(18,\ 18)} = 3.9028$, $P < 0.01$) of the coastal station. Seasonal difference ($P < 0.05$) in biomass was not prominent in the mixed layer of the oceanic stations ($F_{(3,\ 19)} = 3.4383$, $P < 0.05$) compared to the coastal station. There was no significant seasonal and latitudinal variation of mesozooplankton biomass in the thermocline layer of the oceanic stations. This indicates that the seasonal hydrographic conditions affect the mixed layer mesozooplankton than the thermocline layer. In 300-BT stratum, what all variations observed in Meso biomass in the open ocean, with respect to seasons ($P > 0.05$) with respect to D/N ($P > 0.05$) and with respect to latitudes ($P > 0.05$) were all due to sampling variability. Differences were not significant. In 300-500 stratum in the open ocean seasonal differences were significant at 10% level, ($F_{(3,\ 18)} = 2.3964$, $P < 0.10$). In 1000-500 stratum in the open ocean only seasonal variations were high ($F_{(3,\ 18)} = 3.065$, $P<.07$).Comparing to the coastal and oceanic mesozooplankton, the seasonal difference was more significant in the coastal regions.

3.4 Discussion

The AS, in comparison to other oceans experiences, the seasonal reversal of atmospheric and oceanic surface circulations during the two monsoon periods (Cutler& Swallow,1984; Hastenrath & Greisschar, 1989, Koppel mann & Weikert, 1997; Kumar and Prasad, 1999) i.e. south west and north east monsoons. Most of the biological measurements in the past were usually concentrated only on these two seasons (International Indian Ocean Expedition (IIOE), Plankton Atlas, 1968; Krey and Babernard, 1976; IOBC 1968a &1968b) except for JGOFS. Based on the atmospheric forcing, the entire study area can be divided into four seasons, spring inter monsoon, summer monsoon, fall inter monsoon and winter monsoon. It is noted that there is some seasonal and inter annual variability in the productivity patterns.

During the spring inter-monsoon (March– May), the transition period from winter to summer, the entire AS attains a typical tropical structure (oligotrophy). The winds were predominantly northwesterly (Hastenrath and Lamb, 1979) and the southern region (8°-13°N) was warmer than the (Fig. 3.2) northern region (17-21°N). Prasannakumar &Prasad (1996) reported that during this season, the South Eastern Arabian Sea is exposed to primary heating, when the surface layers become highly stratified as a consequence of mixing of low saline Bay of Bengal water and Arabian Sea high saline water mass (ASHSW). Development of mini warm pools by the low saline waters is also favorable for stratification in the south eastern AS during the spring inter monsoon. The surface waters were fairely saturated (DO > 200) due to the low decomposition. Extensive blooms of blue-green algae *(Trichodesmium)* were observed off Goa and Bombay during this study, (Jyothibabu *et al.*, 2008) *T. erythraeum* was the most dominant phytoplankton species during the SIM was attributed to the warming of surface waters, calmness and high salinity (Devassy *et al.*, 1978, Burkill *et al.*, 1993b). A nutrient depleted condition in the intermediate stations and moderate nutrient rich condition (≈ 60m) in the surface was noticeable. It may be due to the nitrate enrichment, as a consequence of decaying diazotrophic spring blooms (*Trichodesmium*), a prominent ecological alteration developed under oligotrophy. But chl *a* and primary productivity were very low compared to other seasons. Bhattathiri *et al.*, (1996) observed similar conditions over most of the eastern Arabian Sea during the SIM period. The sea surface was warmer (> 29°C) and stratified which restricted the entrainment of nutrients to the surface layers (Madhupratap *et. al.,* 1996 b; de Souza *et. al.,* 1996). This in turn, could reduce the primary production in the region.

During the spring inter monsoon, the mesozooplankton biomass was comparatively high (Table 3.2 &Fig. 3.8a) compared to winter monsoon. The mixed layer biomass was high in the northern region compared to southern regions (Table 3.2&3.5). This finding has been supported by the earlier studies of JGOFS (Wishner *et al.*, 1998).They have showed that in the oligotrophic Spring Intermonsoon condition high mesozooplankton biomass was sustained both in coastal and open ocean waters. Towards the deeper layers, the mesozooplankton biomass decreased sharply (Table 3.2). This sharp decrease in zooplankton abundance with depth is well known (Longhurst, 1980; Angel and Baker, 1982). It is quite possible that the decrease in zooplankton would have started due to oxygen deficiency (Vinogradov and Voronina, 1961), which generally lies between 150 - 900m in the Arabian Sea (Naqvi, 1987). During this season, the dominant component in the mesozooplankton was copepods (>80%) both in the mixed layer and in the thermocline layer (Fig. 3.14 & Table 3.3).The recent study revealed (Jyothibabu *et al.*, 2008) that during SIM the dominant component in the microzooplankton are protozoans and copepod naupli. The high abundance of copepods in the mesozooplankton community would explain the dominance of copepod naupli in the microzooplankton community. The phytoplankton community during this period consisted of smaller diatoms and cyanobacteria (Nair *et al.,* 1992; Sawant and madhupratap,1996; Anoop *et al.*, 2007). The copepod nauplii are capable of surviving in tropical oligotrophic waters by feeding alternately on bacteria and picoplankton (Roff *et al.*,1995),where as other carnivorous copepods and larger zooplanktons are unable to crop the smaller sized phytoplankton efficiently (Marshall,1973). Thus microzooplankton plays a vital role in transferring the primary organic carbon (from the smaller phytoplankton), to mesozooplankton. Studies by Roman *et al.*, (2000) and Calbet *et al., (*1999) report that microzooplankton is an essential diet for mesozooplankton during oligotrophic condition. Dominance of copepods in the mesozooplankton composition may have some relation to the *T.erythrium* blooms during SIM. Some of the copepods, especially the harpacticoid copepods such as *Macrosetella gracilis* use *Trichodesmium* as a food as well as physical substrate to juvenile development (O' Niel *et al.*, 1998). Haridas and Rao (1981) had listed the copepod genera Macrosetella that are common for the epipelagic region in the Arabian Sea.

During summer monsoon (June– September), the southwesterly winds move the surface waters away from the southwest coast of India (Fig. 3.1). The coastal upwelling was evident from the vertical profile of temperature, salinity and nutrients (Figs. 3.3&3.6). The presence of cold waters near the coast and SST gradient between the coastal and open ocean stations also support the earlier reports (Shetye *et al.*, 1990; Sanilkumar *et al.*, 2004). Coastal upwelling and/or freshwater influx (riverine influx, precipitation and land runoff) may be the reason for shallow MLD along the coast in contrast to the deep MLD of offshore which is effected by strong and steady monsoon winds. Strong upwelling was noticed at 8° and 10°N and weak at 13°N, indicating the gradual propagation of the upwelling from south to north. Further north of 13°N, the upwelling was very weak possibly due to the effect of the southward movement of ASHSW (Muraleedharan and Prasanna Kumar, 1996; and Sanilkumar *et al.*, 2004). The northern AS showed deep MLD at south and shallow MLD at north of the Findlater jet (Bauer *et al.*, 1991). The high chlorophyll concentration (41 mg C m^{-2}) and primary productivity (613 mg C m^{-2} d^{-1}) observed in the southern coastal regions can be attributed to the result of upwelling. Thus upwelling of subsurface waters brings nutrients to the euphotic zone and eventually results in the high biological production in the coastal region off 8°N and 10°N. During upwelling the surface waters are replaced by cool, nutrient-rich and oxygen-deficient waters from the subsurface (Banse, 1968; de Souza *et al.*, 1996; Bhattathiri, 1996). The Findlater jet flowing across the Arabian Sea is favorable for an open ocean upwelling in the northern region, evidenced by relatively low SST's (26.34 to 28°C). It was observed excessive growth of phytoplankton with relatively high phaeopigments in the southern coastal regions.

In the present study, compared to other seasons, the highest biomass was recorded during summer monsoon along the coasts 8 10°N (Fig. 3.13). A pronounced enhancement in the mesozooplankton biomass along the southwestern coast of India, during the summer monsoon period has been reported by Panikkar, (1968) Haridas *et al.*, (1980); Madhupratap and Haridas,(1990). The composition of zooplankton showed (Fig. 3.14) copepods were the dominant community except at the southern coastal regions, where their percentage contribution was almost similar to other carnivorous zooplankton such as siphonophores, euphausiids, medusa,chaetognaths. The similar distribution pattern was observed by Paulinose et al (1977). Madupratap *et al.*, (1990) reported that the dominant representatives of copepods were herbivorous or omnivorous calanoides. Diversity of mesozooplankton was also less in the upwelling regions, as only a few taxa form majority of population in the coastal upwelled waters. In this study shoals of sardine juveniles were observed, which may be due to the excessive growth of phytoplankton which attracts the fishes to this region. Offshore and northern regions of AS, biomass values were low compared to upwelled regions, but there values were generally higher than that recorded in other non upwelling seasons. This pattern was previously documented by Madupratap *et al* (1990). Due to the down welling effects MLD in the region south of the Finlater jet is deep to about 100 m, but to the north of it the positive wind stress curl causes shoaling of the thermocline indicating open ocean upwelling. (Bauer *et al* 1991, Prasanna kumar *et al.*, 2000), to enhance open ocean production during summer. During the early stages to the peak of upwelling periods, the herbivorous zooplanktons were replaced by carnivorous Euphausiids and siphonophore, which sustenances a high mesozooplankton biomass in the southern coastal regions. Nutrient enrichment by upwelling in the southern coast supports the primary production which, in turn, sustains the herbivorous zooplankton by followed by carnivorous zooplankton. As a result, the organic production was completely utilized by the higher trophic level organisms leading to a reduction in export flux, compared to northern regions.

A more or less similar scenario prevails during fall Intermonsoon (September–October); The transition of summer to winter monsoon represents the retreat of the southwest monsoon. Warm (SST ~ 28°C), shallow mixed layer (~ 20–30 m) and strong stratification were observed during this period (Fig. 3.3&3.4). Waters along the south west coast of India (8°N, 10° and 13°N) were characterized by the upsloping isotherms towards the coast. During this period, vertical transports were weak since the surface currents were retarded (Culter and Swallow, 1984). The vertical profiles of DO showed a sub surface depletion of dissolved oxygen. Naqvi *et al* (2000) have reported intense suboxic conditions along the west coast of India during October, primarily because of upwelling. The depth of the nitracline and mixed layer shallows on approaching the coast and hence the biological production was relatively high near the coast (691mg C m^{-2} d^{-1}). In the open ocean region of the south west coast of India, the convergence of surface waters was evident, which can be explained through the intensification of the upwelling during the summer monsoon that eventually transport the surface waters offshore and by September it might converge in the open ocean region, leading to a deep nutrient depleted mixed layer and transform the region into an oligotrophic condition. North of 13°N, the up sloping of isolines are confined between 25 and 100 m, implying that upwelling was in the retrieval stage in north, while it was still active along the southwest coast of India. This supports the views of Banse (1959; 1968), that upwelling along the southwest coast of India starts with the onset of southwest monsoon and reaches the maximum intensity during July – August, and ends by mid-October. A general increase in the biological production was evident in the coastal region and a decrease in the open ocean region during fall intermonsoon.

On approaching the coast, the nutrient concentrations enhanced and a relatively high biological production (691 mg C $m^{-2}d^{-1)}$ In October, even after the summer monsoon, enhanced biological production appears in the upwelling zones (Banzon *et. al.,* 2004). A second peak in the mesozooplankton biomass (0.44ml.m^{-3}) was seen during this season after the summer monsoon peak (1.47 ml.m^{-3}). The zooplankton biomass was maximum along the coast than in the oceanic stations (Table 3.4). It is interesting that compared to the north and south, NEAS sustains high zooplankton biomass. The presence of high abundance of microzooplankton (Madhupratap *et al.,* 1996a, b). Ramaiah *et al* (1996) and Burkill *et al* (1993b) are probably supporting high mesozooplankton during this season (Madhupratap *et al.,* 2000). Less biomass in the southern open ocean was consistent with findings of the JGOFS (Madhupratap *et al.,* 1996b; Stelfox *et al.*, 1999). A few data sets were available for the fall inter monsoon from the open ocean regions of the northern AS (av.65-127m mole Cm^{-2}) in the upper 200 m (Kumari and Achuthankutty,1989; Madhupratap *et al.*, 1992). The mesozooplankton had the abundance of copepods (>80%) during this season, and agrees fairly well with the observation of Madhupratap *et al.,* (2000).

During winter monsoon, the northwest and southwest coasts of India exhibited two contrasting scenarios. Along the southern transects, sea surface was comparatively warm and low saline, but the surface waters in the northern transects was cool (SST ~ 24°C) and high saline. The low saline waters along the southwest coast of India could be attributed to the intrusion of Bay of Bengal waters. The cool and dry continental air brought by the prevailing northeast winds enhance the evaporation in the northern AS which leads to the surface cooling and initiates the convective overturning. This was clearly seen along 17°N and 21°N as a weakly stratified cold and deep mixed layer. Densification of surface waters in turn, leads to deep MLDs injecting nitrate into the surface layers (2–4 µM) and accelerate biological production (Banse and McClain, 1986; Madhupratap *et al.*, 1996; Jyothibabu *et al.*, 2003; Balachandran *et al.,* 2008)

The resultant high chlorophyll *a* (av.39 mg m^{-2}) and primary production in the northern AS is attributed to nutrient enrichment by convective mixing. Many workers have reported winter convection and associated enhanced production in the northern AS (Banse, 1987; Bauer *et al.*, 1991; Madhupratap *et al.*, 1996; Prasanna Kumar *et al.*, 2001b). The mesozooplankton biomass was very low in the northern AS during winter monsoon and was represented by carnivorous group. The reduction in the herbivorous zooplankton may be due to the presence of larger diatoms. The carnivorous zooplankton was not contributing to the total mesozooplankton biomass because the microzooplankton density was kept low by low temperature (Mangesh, 2000). The primary production was almost equivalent along the upwelling regions and winter cooling regions, but the secondary production was not as high as in the upwelling region. The grazing of microzooplankton and herbivorous mesozooplankton were poor in the northern AS, due to the dominance of carnivorous zooplankton, as a result the unutilized organic carbon at the euphotic zone sinking to intermediate depths for oxidation, leading to a eutrophic condition. Naqvi *et al.,* (1987) reported the denitrification zone and the oxygen minimum zone were prominent due to the high export flux in the northern AS than the Southern AS. The estimated vertical flux was centered on the northern oceanic stations, a region characterized by high rates of column production (Sarin *et al.*, 1996).

The composition of mesozooplankton showed that most of the carnivorous groups (chaetognaths, ostracods, siphonophores and hydrozoans) were dominant in the northern AS (Fig. 3.14&Table 3.3). Ostracods were the second dominant group (42%) and their contribution was high (51%) in the thermocline layer during winter monsoon (Fig. 3.14). Among ostracods, the dominant species

Cypridina dentata was always coincident with cold, high saline and highly productive waters. The high saline water of the Arabian Sea (ASHSW) is probably the only water mass (salinity >36, temperature <26°C) sustaining high abundance of *Cypridina dentata.* Therefore, this species form an indicator to trace the presence and spreading of ASHSW (Jasmine *et al.*, 2007).

The results showed that there were significant differences in the mesozooplankton biomass between the seasons and over the latitudes. Differences were prominent in the mesozooplankton biomass in the mixed layer ($P < 0.01$) of both coastal and open ocean waters ($P < 0.05$). In JGOFS collection, the mixed layer mesozooplankton biomass in coastal and open ocean waters ranged between 25-120ml.100m^3 or between seasons, whereas it was between18-147ml.100m^3 in this study. Biomass based on JGOFS collections were not compared with the present study, because the JGOFS collections were from a single location in the open ocean and a coastal transect. During the oligotrophic condition, mesozooplankton depends on the microbial loop, but zooplankton biomass varied significantly between seasons and latitudes. So this study was in incongruity with the validity of the Arabian Sea paradox, that zooplankton biomass remains more or less invariant, despite seasonally varying primary production regimes, which could be explained by a microbial loop (Madhupratap *et al.,* 1996)

In addition, it can be concluded that, two distinct marine ecosystems are identified in the Eastern Arabian Sea namely, the North East Arabian Sea Ecosystem (NEASE) and the South East Arabian Sea Ecosystem (SEASE) that lie broadly north and south of the Findlater jet. NEASE extends between 15° to 22°N and SEASE between 8° to 15°N latitudes. The physical forcings, energy transfer and the structure of the biotic community of these ecosystems are remarkably diverse, justifying the need to treat them as two distinct ecosystems (Table 3.5). During SM, the SEASE is under the influence of upwelling all along the coast as evidenced by the lifting up of the 26°C isotherm towards the coast, low SST's (26°C), high nutrients ($NO_3 > 1 \mu M$) low dissolved oxygen (~190 μM) in the surface waters. The nutrient rich upwelled waters are transported offshore up to ~200 km by the combined actions of Ekman transport and westward propagating Rossby waves, transferring the entire shelf region of SEASE to an area of high primary production. This is followed by a proportionate increase in zooplankton biomass (5 $ml.m^{-3}$), thereby striking a balance between primary production and grazing, which explain the limited export flux and sinking of organic carbon to deeper waters of SEASE in comparison to NEASE. At the primary consumer level herbivory is dominant due to the abundance of grazing zooplanktons (Copepods, Euphausiids) and larvae and adults of herbivores fishes like *Sardinella longiceps*. The influence of summer monsoon on NEASE are rather limited to the zone of divergence north of Findlater jet, where open ocean upwelling occurs as evidenced by relatively low SST's (26.34 to 28°C) and chlorophyll *a* > 1 mg m^{-3} This area of the NEASE appears to be a major breeding ground of the Myctophid *Diaphus arabicus* (Madhupratap *et al.,* 2001). During the season, the area is covered by the Arabian Sea High Saline Waters (ASHSW) with surface salinity >35.50 and 36.00 for coastal and open ocean waters, respectively. SST varied between 28.5 to 29°C. Primary productivity ranged from 3.81 mg C m^{-3} d^{-1} in coastal waters to 4.15 mg C m^{-3} d^{-1} in the open ocean.

Productive season in NEASE corresponds to the winter monsoon. Under the influence of the cold and dry north easterlies, surface water along the coast and Open Ocean becomes denser and sinks, causing convictive mixing of waters. These maintain the supply of nutrients to the surface and promote primary production (13 to 27 mg C m^{-3} d^{-1}),but the secondary production is rather low (0.2 to 0.4 ml. m^{-3}). Carnivory is dominant, in view of the abundance of zooplanktons such as Chaetognaths, Ostracods and carnivorous fishes like *Harpadon nehereus*, Ribbon fishes etc (Madhupratap *et al.*, 2001). During WM season, SEASE is characterized by SST's, which are higher by 2°C than NEASE, less saline surface waters (~34.00), low primary productivity (2 to 4 mg C m^{-3} d^{-1}) and very low zooplankton biomass (0.1 to 0.2 ml m^{-3}). Thus the fishery habitats of the two ecosystems are also quite diverse.

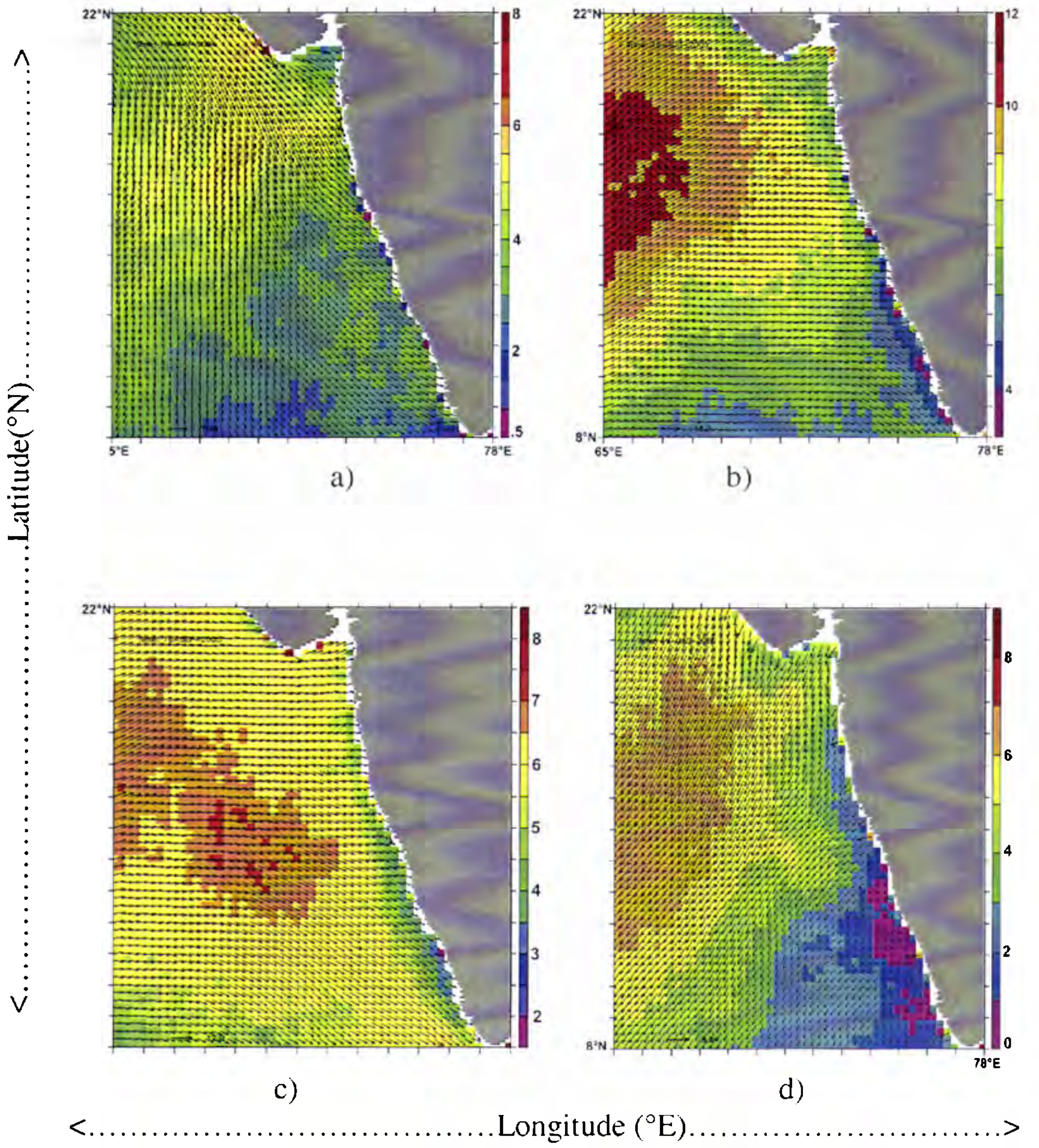


Fig. 3.1 Wind Pattern in the AS during a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon

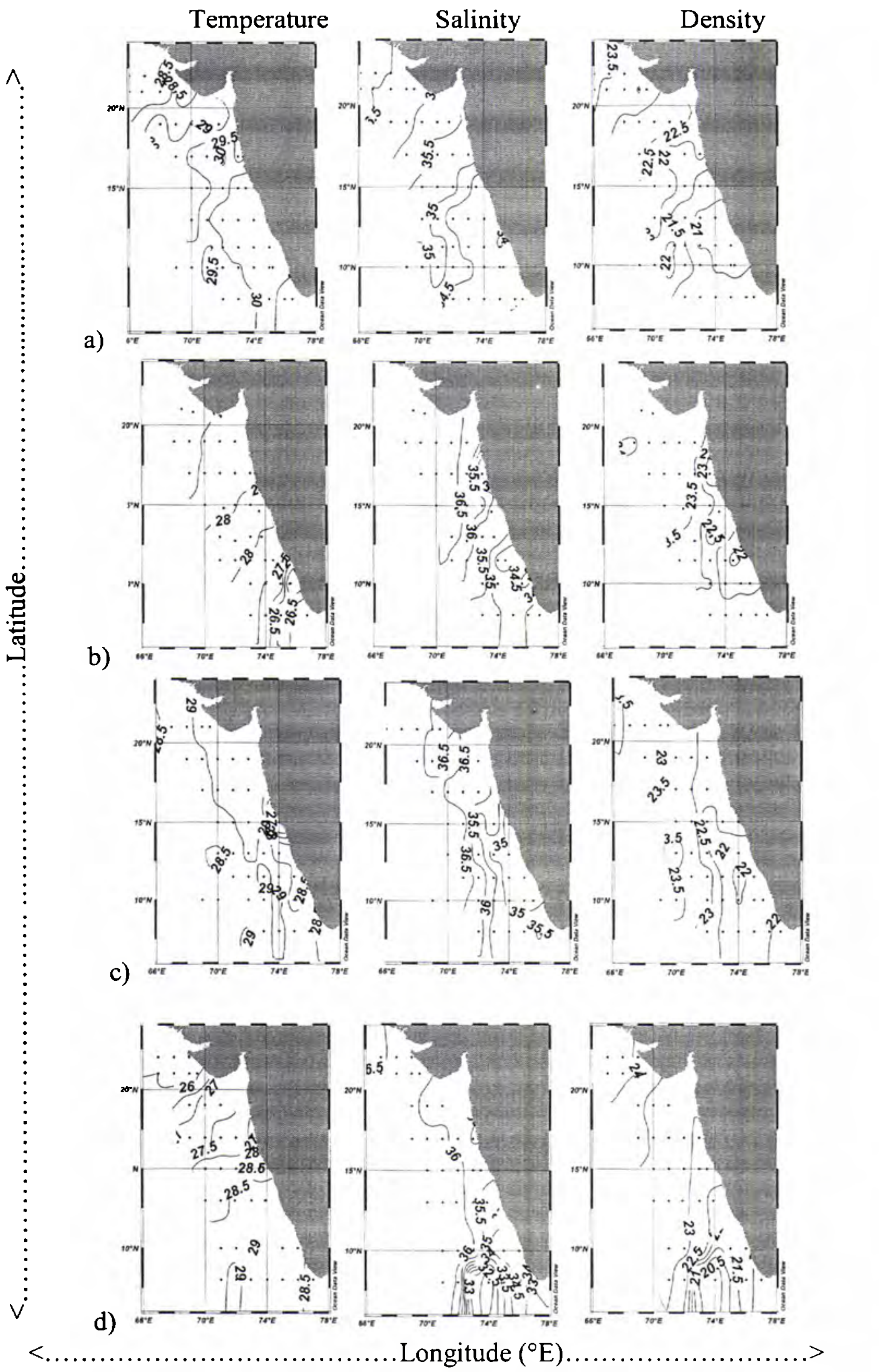


Fig. 3.2 Spatial distribution of Surface Temperature (°C), Salinity and Density in the Arabian Sea during a) Spring inter monsoon b) Summer monsoon c) Fall inter monsoon d) Winter monsoon

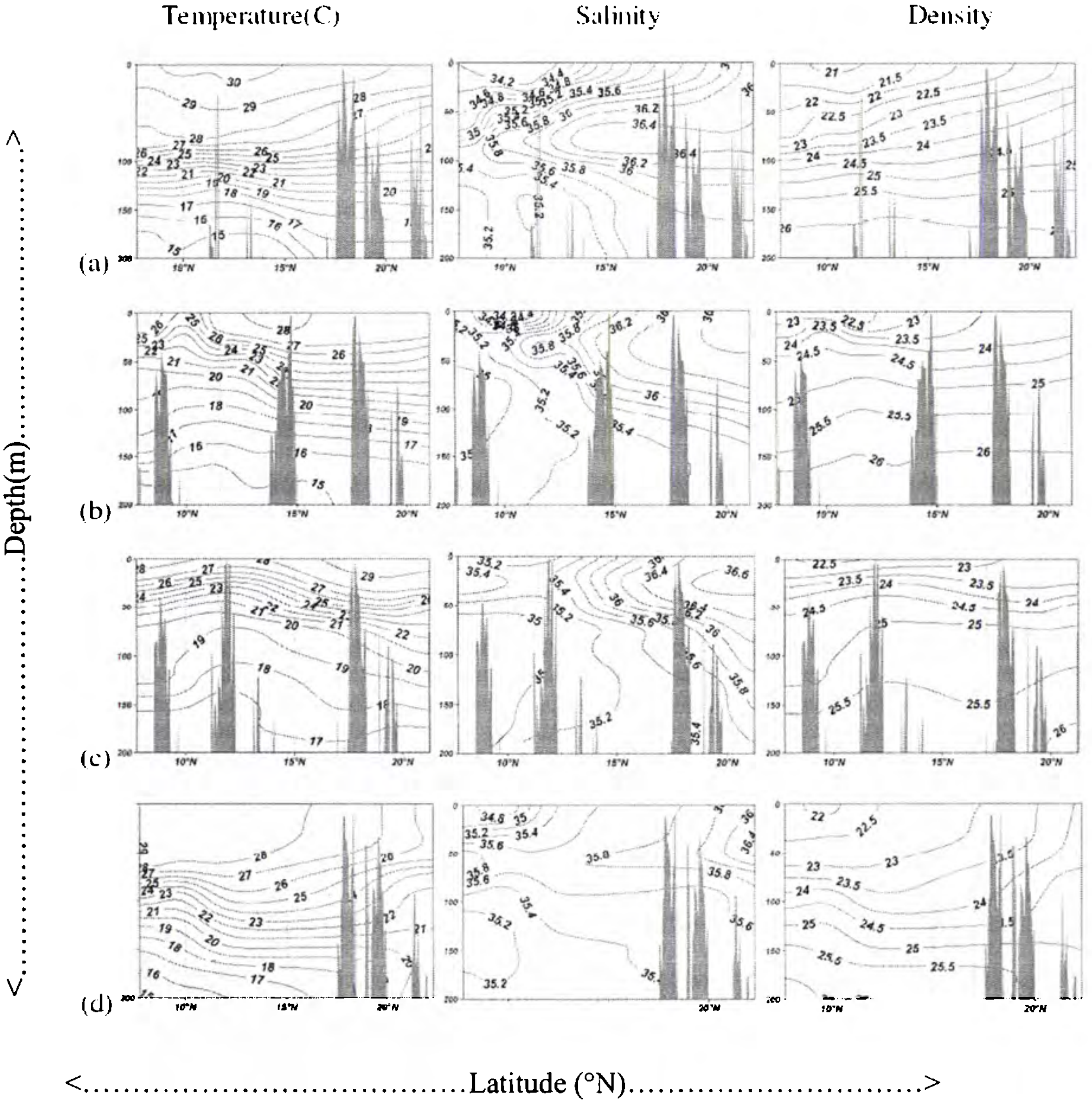


Fig. 3.3 Vertical distribution of Temperature (°C), Salinity and Density in the coastal stations of the Arabian Sea during a) Spring inter monsoon b) Summer monsoon c) Fall inter monsoon d) Winter monsoon

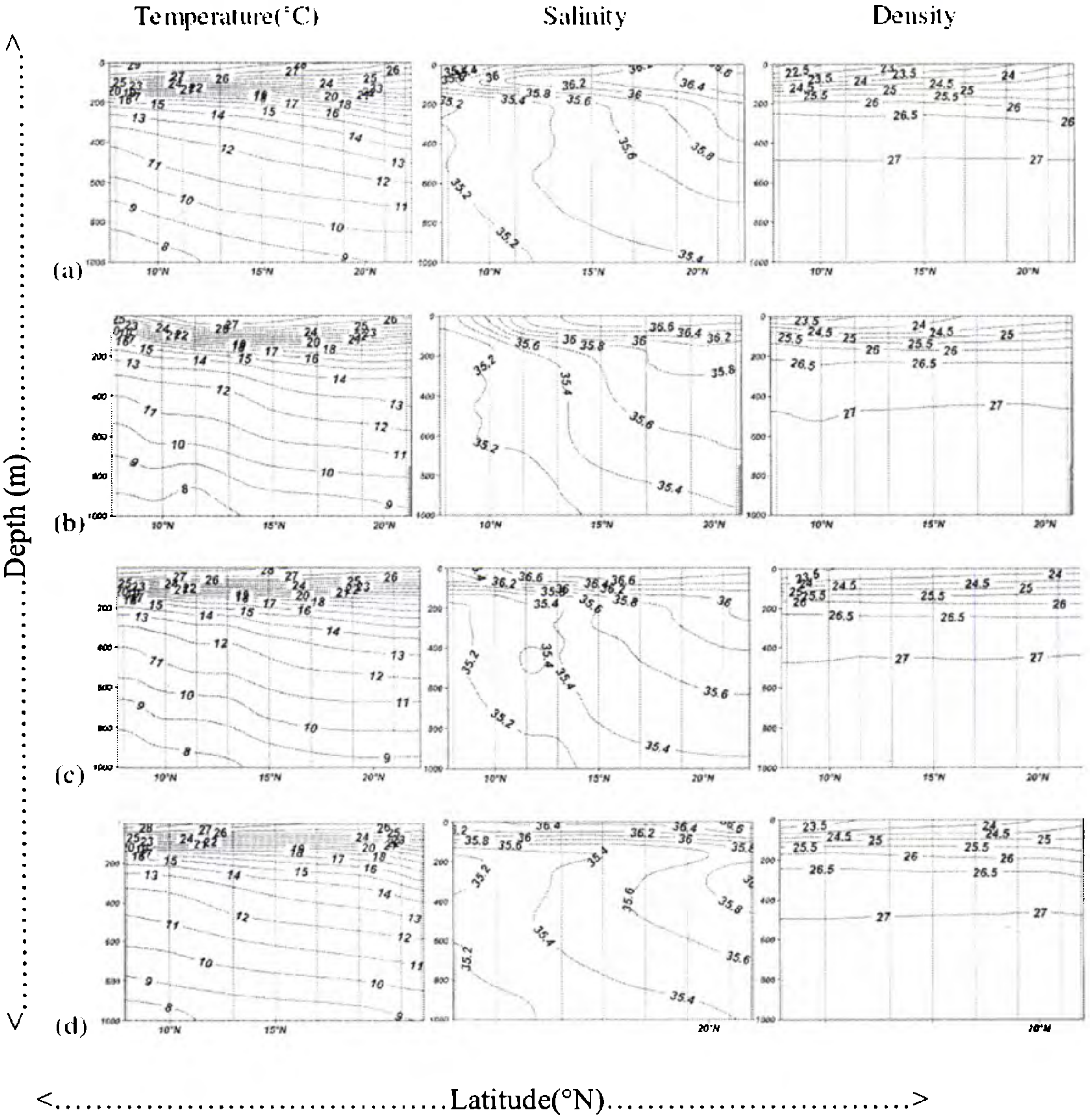


Fig. 3.4 Vertical distribution of Temperature (°C), Salinity and Density in the offshore stations of the Arabian Sea during a) Spring inter monsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon

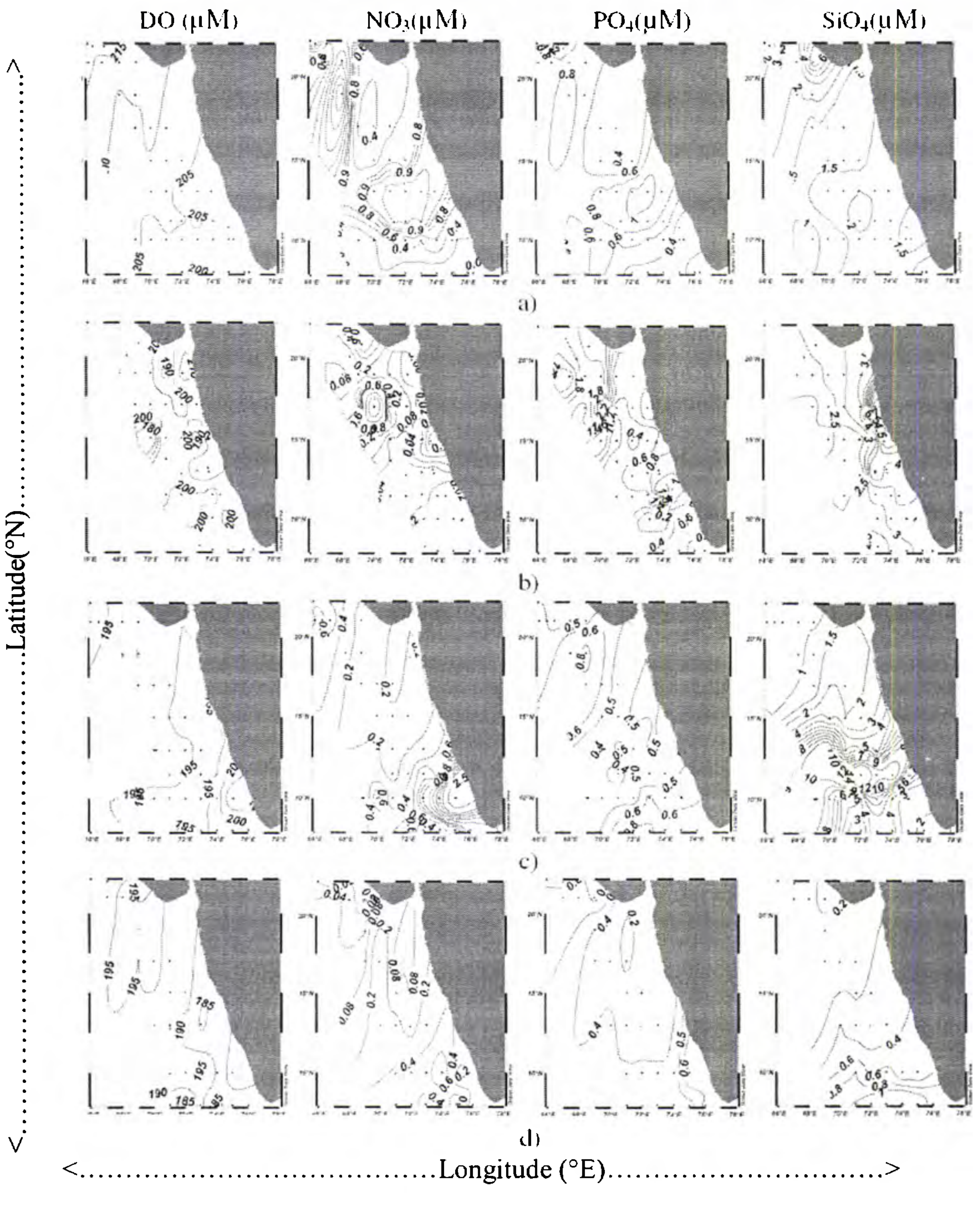


Fig.3.5 Surface distribution of dissolved oxygen (μM),Nitrate (μM),Phosphate (μM),and Silicate(μM),in the Arabian Sea during a) Spring inter monsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon

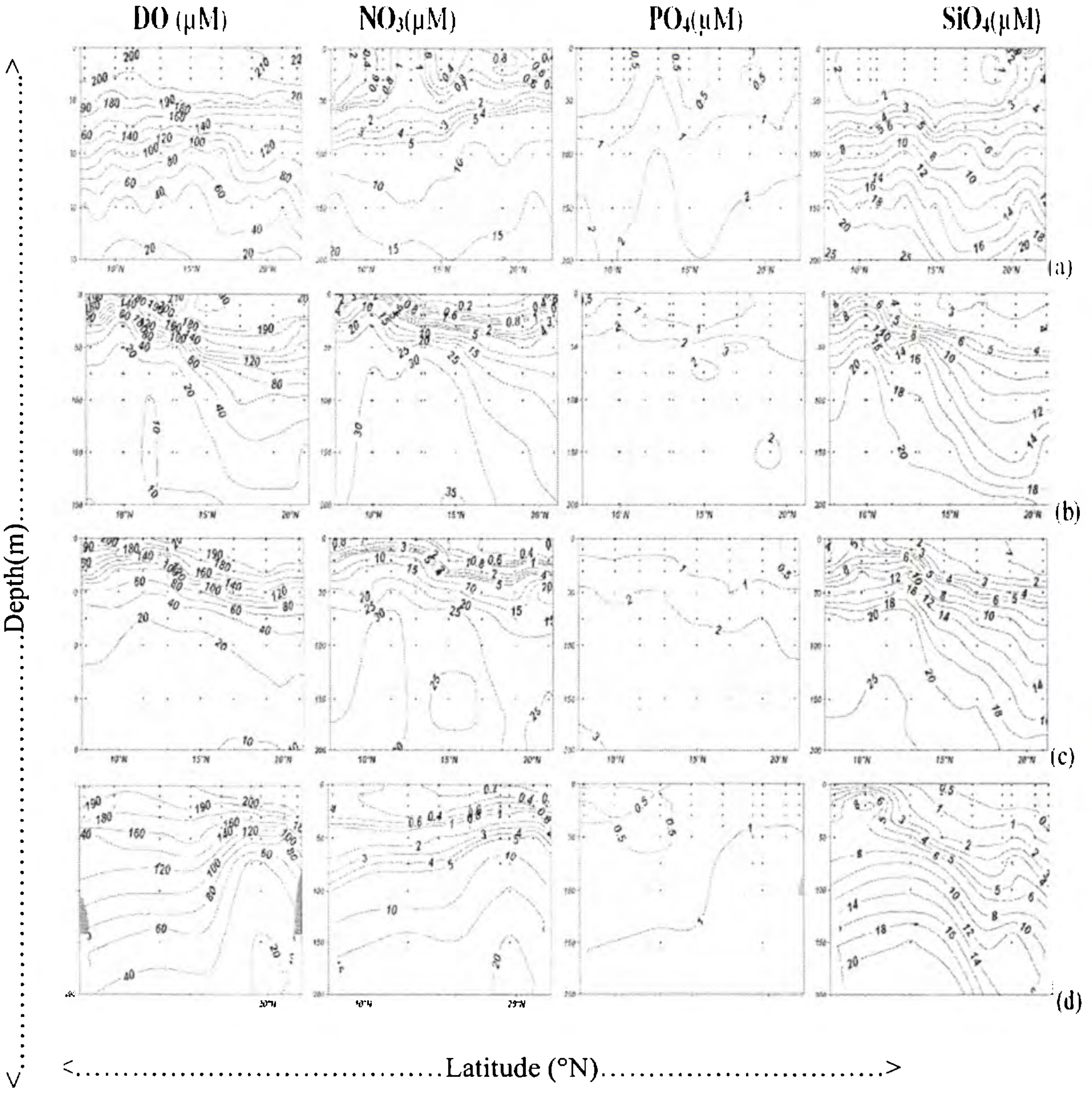


Fig.3.6 Vertical distribution of a)Dissolved oxygen(µM),b)Nitrate c)Phosphate (µM),and d) Silicate (µM),in the Coastal stations of the Arabian Sea during a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.

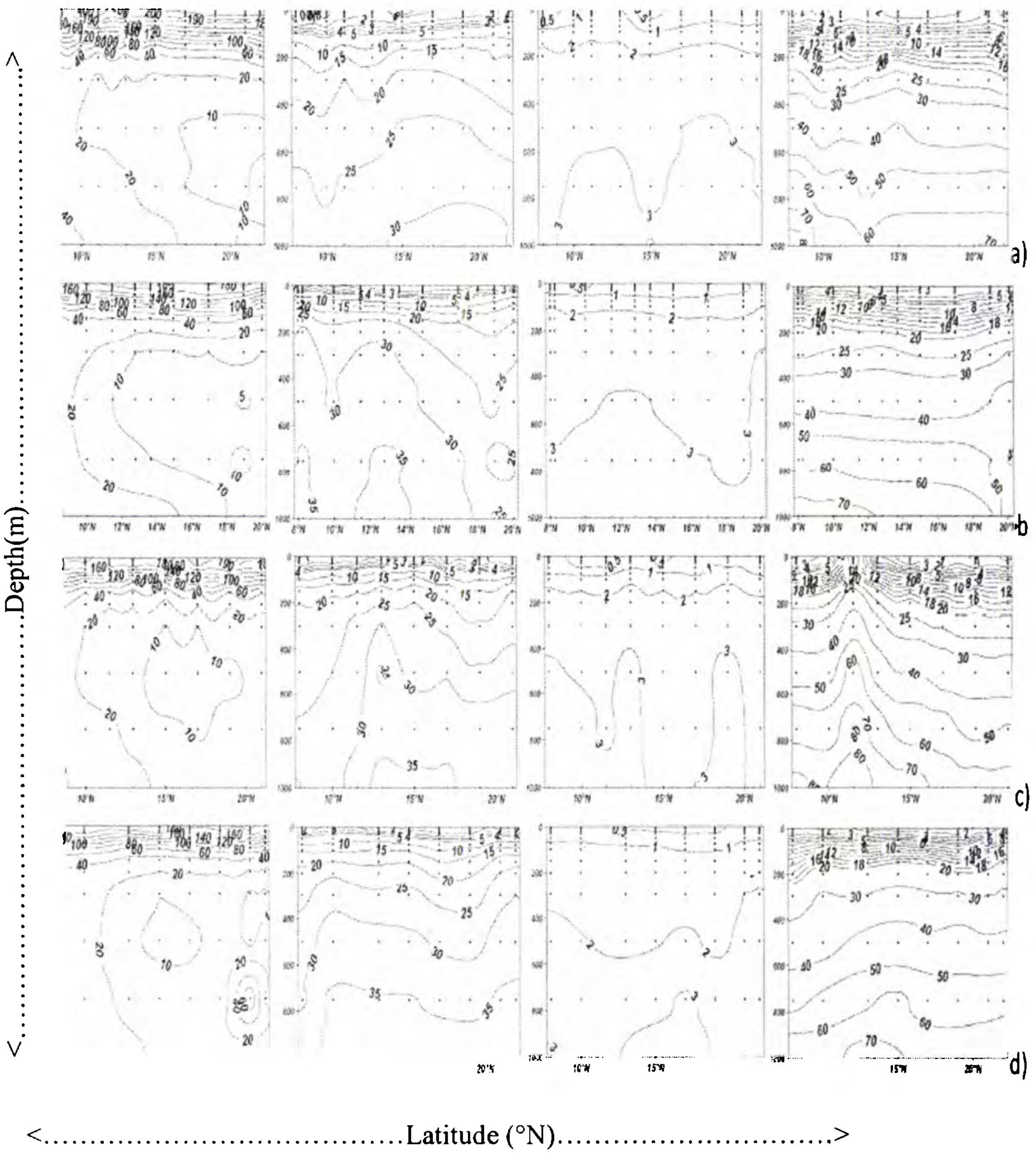
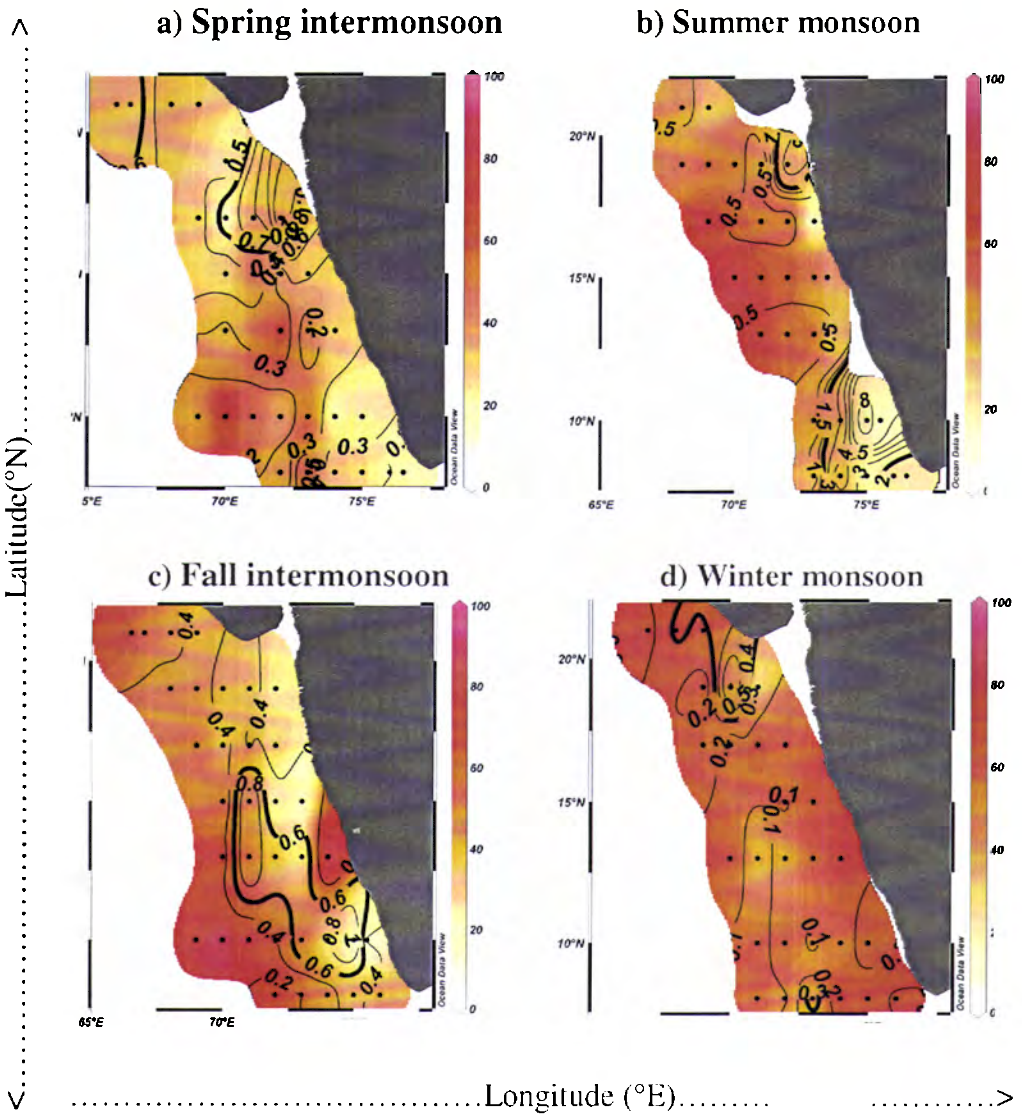


Fig. 3.7 Vertical distribution of a) Dissolved oxygen b) Nitrate c) Phosphate and d) Silicate in the Oceanic stations of the Arabian Sea during a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.



a) Spring intermonsoon

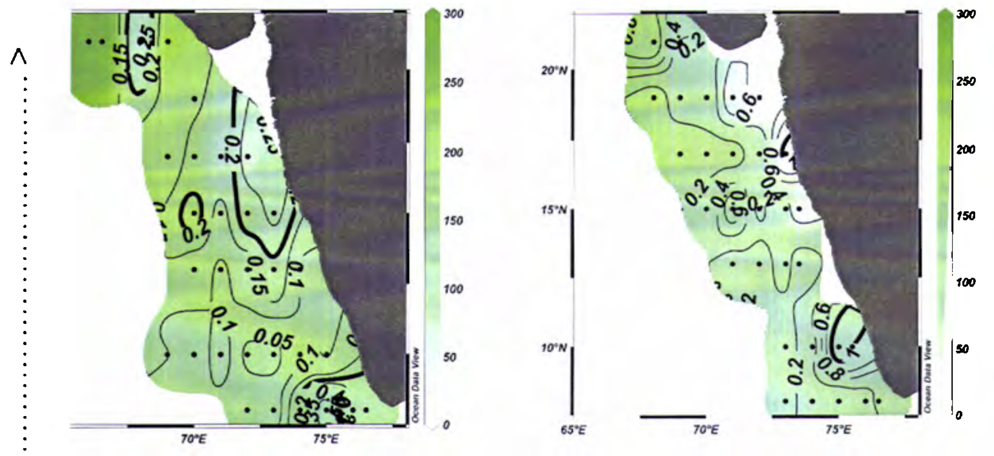
b) Summer monsoon

c) Fall intermonsoon

d) Winter monsoon

Fig. 3.8 **Mesozooplankton** Biomass (ml.m^{-3}) in the mixed layer of the Arabian Sea during different Seasons. Biomass contours are superimposed on the mixed layer depth (m).

a) Spring intermonsoon b) Summer monsoon



c) Fall intermonsoon d) Winter monsoon

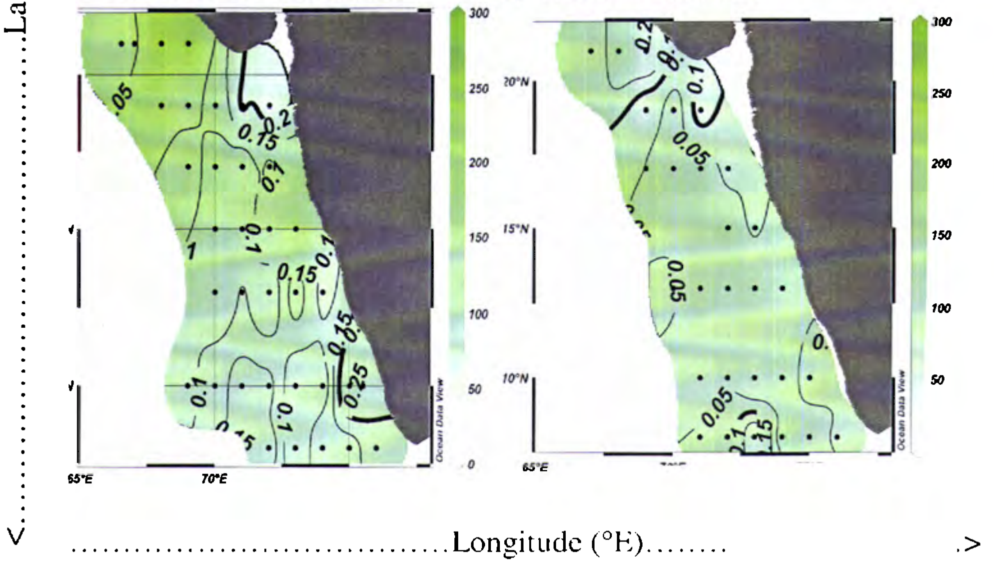
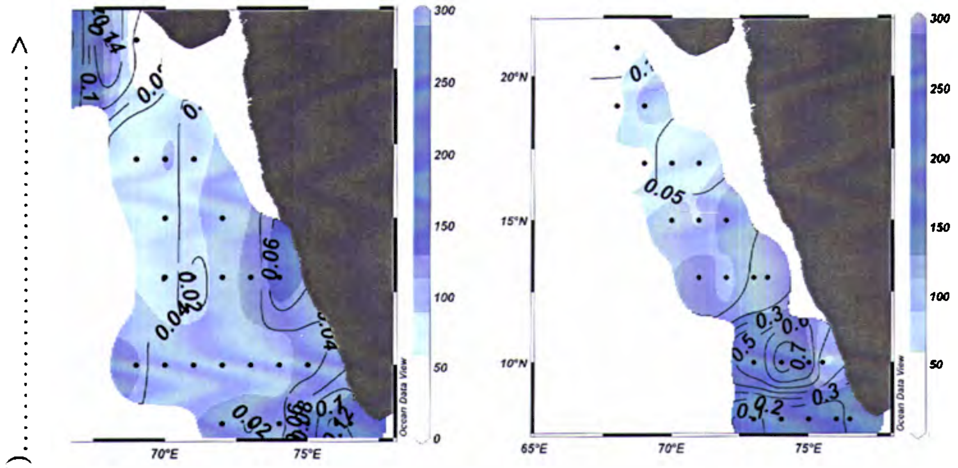


Fig. 3.9 Mesozooplankton Biomass (ml.m^{-3}) in the BT-TT depth of the Arabian Sea during different Seasons Biomass contours are superimposed on the Thermocline depth (m).

a) Spring intermonsoon

b) Summer monsoon



c) Fall intermonsoon

d) Winter monsoon

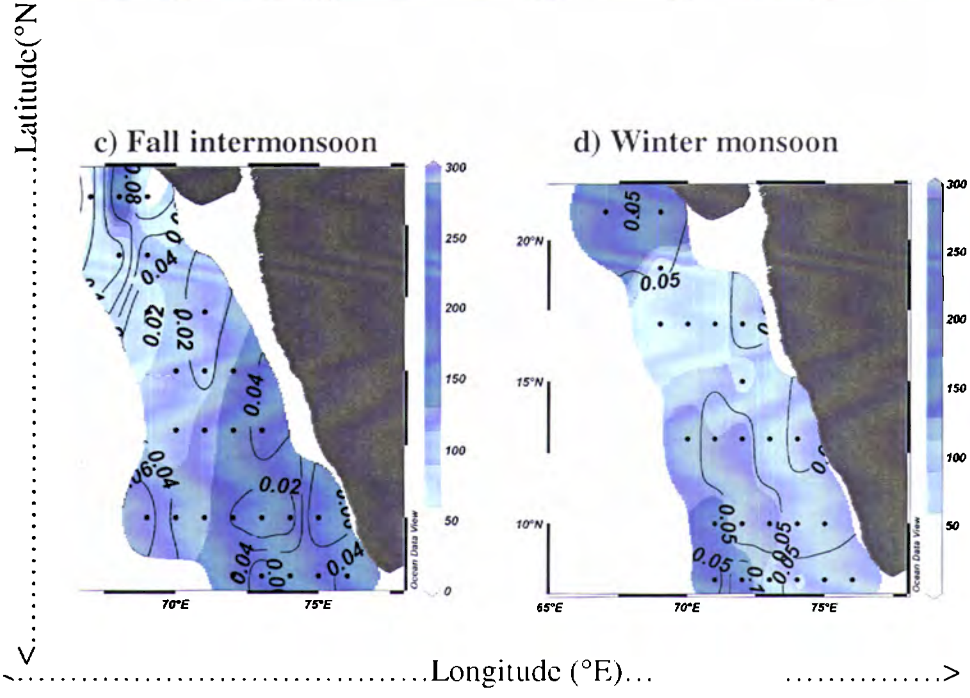
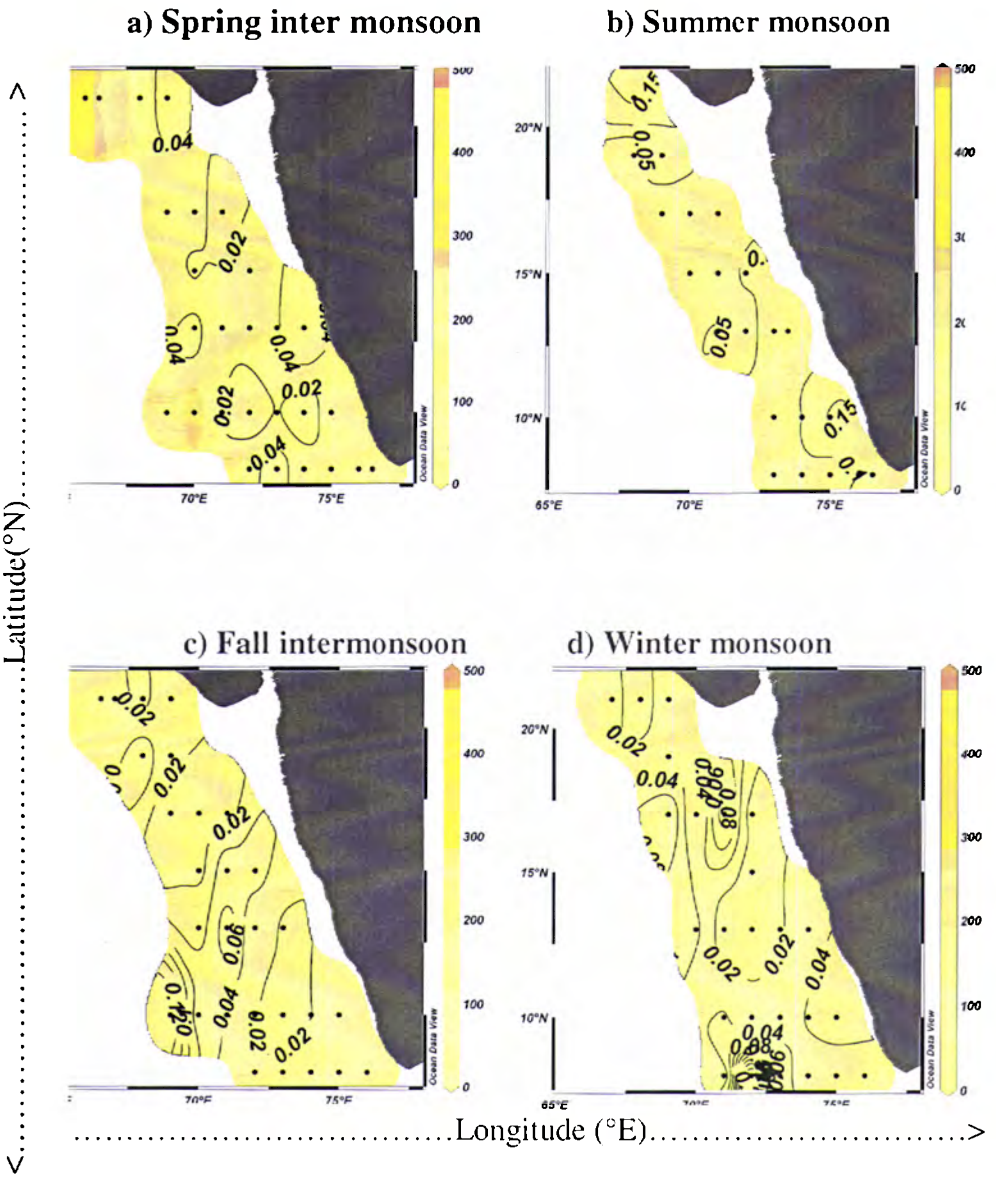


Fig. 3.10 Mesozooplankton Biomass (ml.m^{-3}) in the 300-thermocline depth of the Arabian Sea during different Seasons.



a) Spring inter monsoon

b) Summer monsoon

c) Fall intermonsoon

d) Winter monsoon

Fig. 3.11 Mesozooplankton Biomass (ml.m^{-3}) in the 500-300 depth strata of the Arabian Sea during different Seasons.

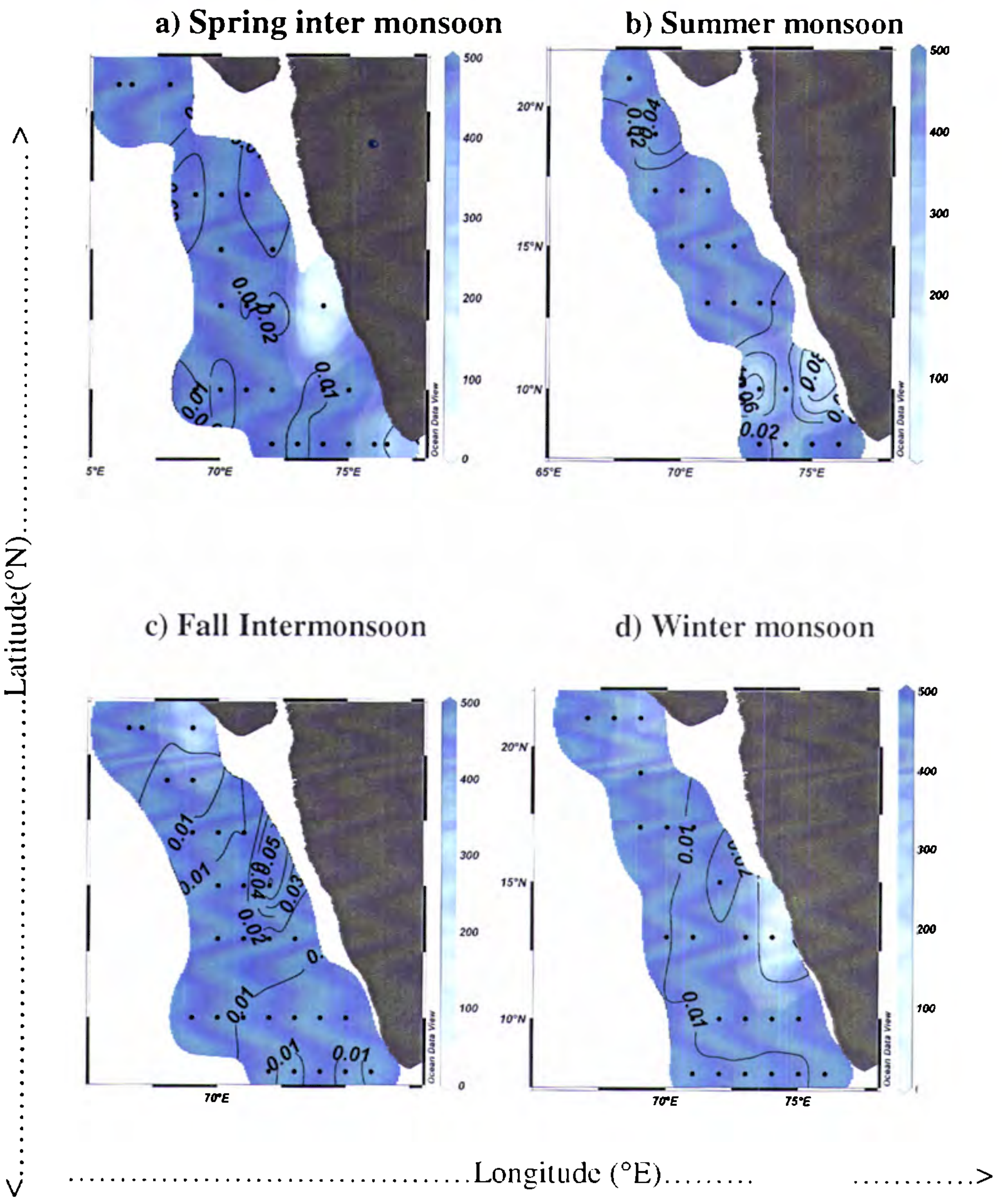


Fig. 3.12 Mesozooplankton Biomass (ml.m^{-3}) in the 1000-500depth strata of the Arabian Sea during different Seasons.

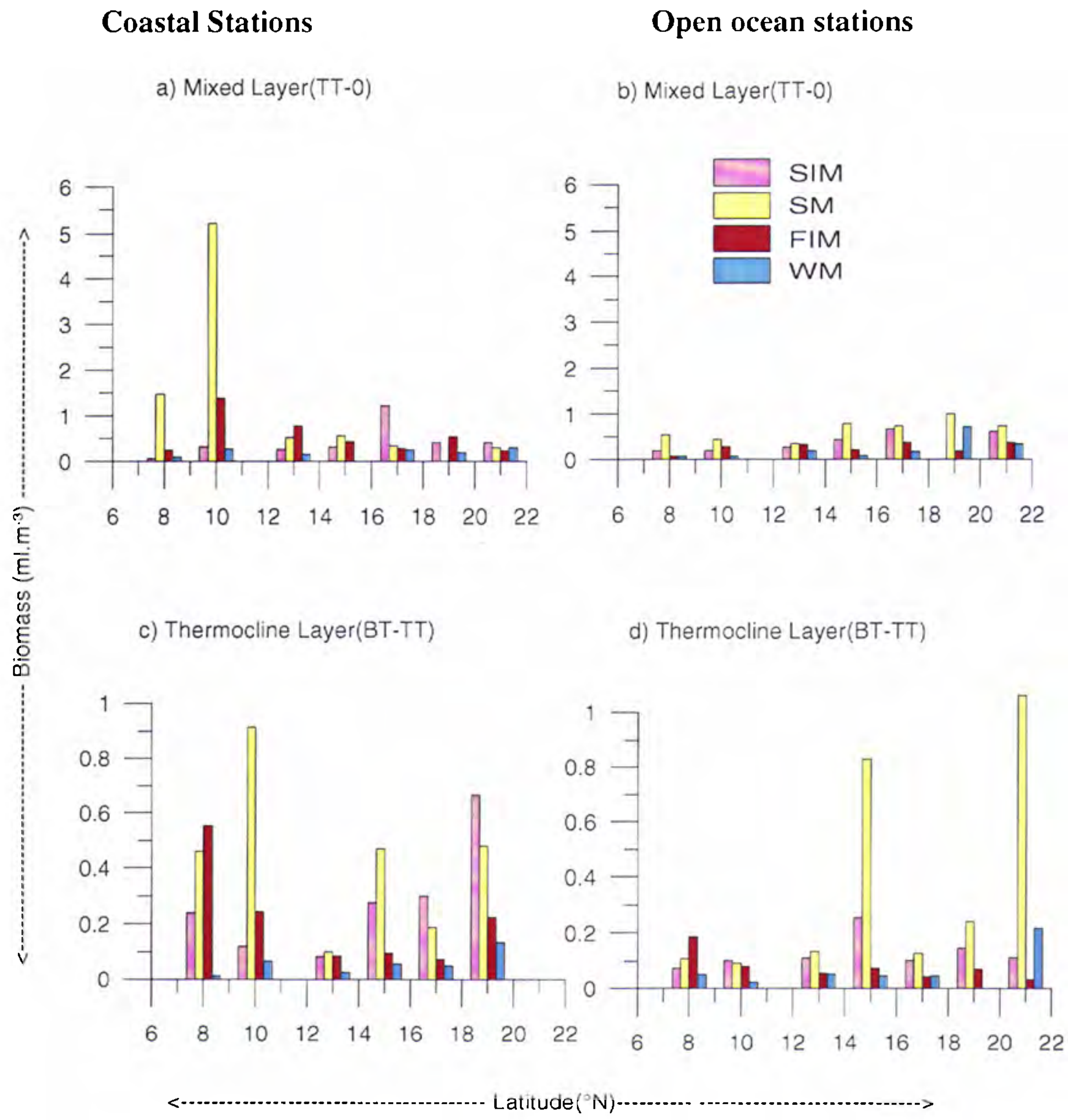


Fig. 3.13 Mesozooplankton Biomass in the coastal and open ocean stations of Arabian Sea during different seasons in the mixed layer and thermocline layer of the Arabian Sea during different seasons.

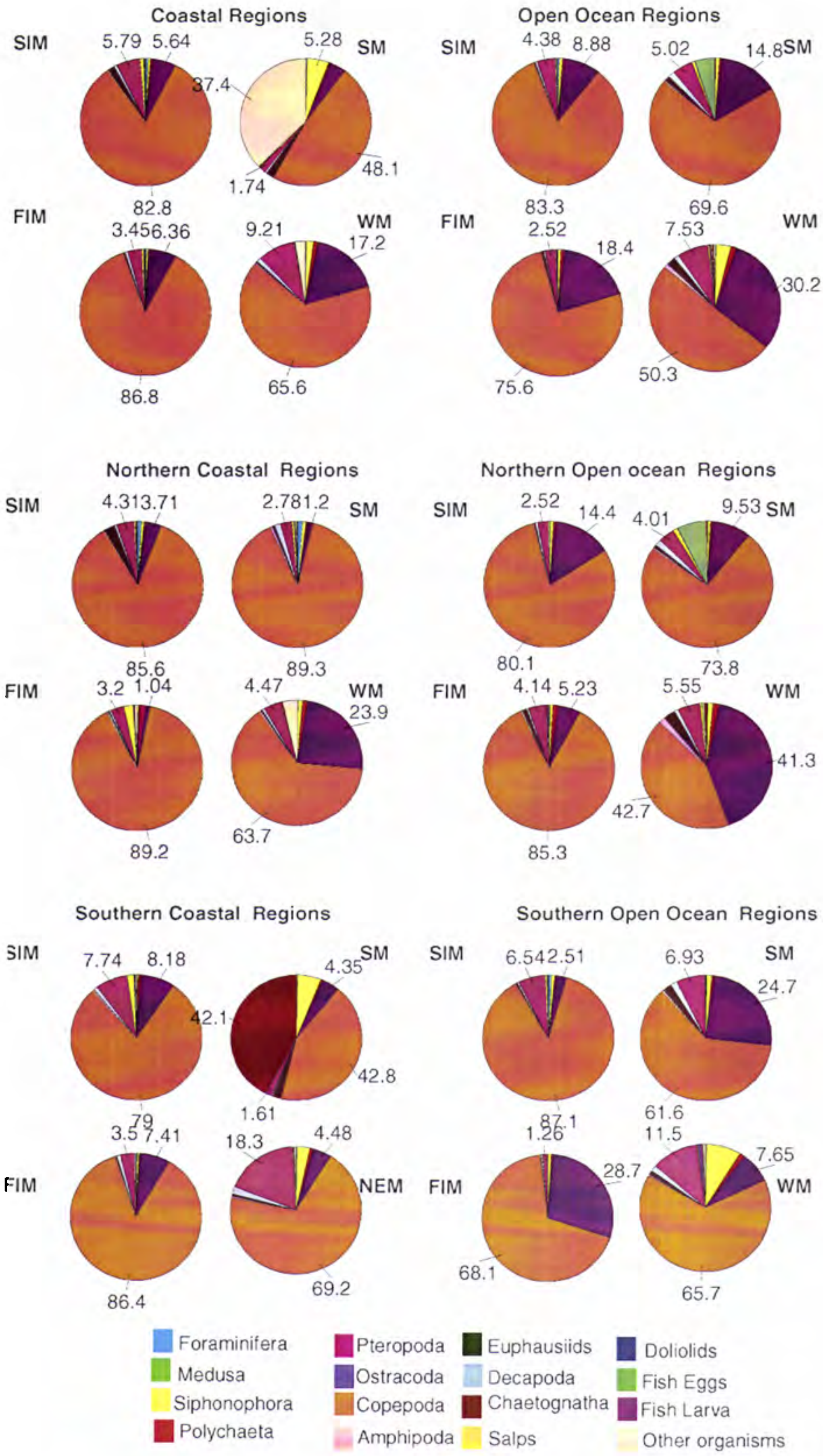


Fig. 3.14 Composition of mesozooplankton in the northern and southern coastal and oceanic stations of the Arabian Sea during various seasons.

Table 3.1 Chlorophyll a (mg m^{-3}) and primary production (mgCm^{-3} d^{-1}) in the Arabian Sea during different seasons. 'C' and 'O' represents the coastal and oceanic stations

Season			**Arabian Sea**			
			Surface Chl *a* (mgm^{-3})	**Column Chl *a*** (mgm^{-2})	**Surface Primary production** (mgCm^{-3} day^{-1})	**Column primary production** (mgCm^{-2}day^{-1})
Spring	North	C	0.27	24.07	2.10	201.59
		O	0.09	9.11	1.01	97.25
	South	C	0.22	15.62	4.74	182.62
		O	0.13	23.12	2.88	129.15
Summer	North	C	0.23	17.44	3.81	293.65
		O	0.21	24.60	4.17	434.95
	South	C	1.10	41.13	43.80	613.14
		O	0.26	19.22	5.40	293.61
Fall	North	C	0.33	21.50	7.03	235.05
		O	0.16	16.07	7.21	175.73
	South	C	0.53	33.85	15.40	691.21
		O	0.26	25.90	5.65	341.14
Winter	North	C	1.09	58.77	26.62	1396.78
		O	0.58	38.67	13.34	944.83
	South	C	0.25	21.46	3.83	375.13
		O	0.23	12.06	2.97	282.35

Table 3.2 Mesozooplankton biomass (ml.m^{-3}) in the Arabian Sea during different seasons.

Seasons	**Biovolume (ml.m^{-3})**			
	Spring Inter monsoon	**Summer monsoon**	**Fall intermonsoon**	**Winter monsoon**
Mixed Layer	0.4	1.47	0.44	0.18
Thermocline	0.16	0.34	0.12	0.04
300-BT	0.04	0.18	0.04	0.052
500-300	0.02	0.06	0.03	0.048
1000-500	0.01	0.02	0.011	0.011
Upper 1000m	0.59	2.07	0.617	0.3

Table. 3.3 Mesozooplankton composition in the different depth layers of the Arabian Sea during different seasons

Seasons	IntermonsoonSpring			Summer monsoon			Inter monsoon fall			Wintermonsoon		
	Depth strata (m)											
Mesozooplankton taxa (%)	MLD	BT TT	Upper 1000m	MLD	BT TT	Upper 1000m	MLD	BT-TT	Upper 1000m	MLD	BT TT	Upper 1000m
Foraminifera	0.11	0.46	0.20	0.04	0.48	0.12	0.18	0.22	0.20	0.14	0.22	0.15
Medusa	0.05	0.11	0.07	0.14	0.18	0.14	0.04	0.04	0.04	0.35	0.24	0.32
Siphonophore	0.41	0.64	0.45	2.84	0.58	2.33	0.79	0.58	0.72	1.97	1.52	1.94
Anthozoa	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaeta	0.27	0.56	0.35	0.11	1.79	0.43	0.38	0.44	0.42	0.70	1.34	0.90
Pteropoda	0.31	0.57	0.38	0.18	0.11	0.16	0.25	0.24	0.24	0.43	0.15	0.37
Heteropoda	0.04	0.02	0.03	0.01	0.05	0.02	0.02	0.00	0.02	0.06	0.07	0.06
Gastropoda	0.08	0.03	0.06	0.04	0.06	0.05	0.08	0.11	0.09	0.33	2.22	0.71
Cephalopoda	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
Cladocera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.89	0.61
Ostracoda	7.96	7.57	7.43	12.14	17.06	12.77	9.89	13.86	10.90	12.84	31.06	15.45
Copepoda	83.83	81.24	83.86	59.75	69.04	62.71	83.27	81.54	82.81	71.30	54.59	68.78
Amphipoda	0.26	0.24	0.24	0.15	0.27	0.17	0.35	0.07	0.27	0.40	0.73	0.44
Euphausiid	0.31	1.24	0.58	0.84	3.72	1.44	0.37	0.32	0.39	0.59	0.86	0.80
Decapoda	0.59	0.56	0.56	0.86	0.95	0.86	0.76	0.39	0.67	1.34	0.54	1.24
Stomatopoda	0.00	0.00	0.00	0.02	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.01
Chaetognatha	4.61	3.77	4.20	3.49	4.08	3.51	3.24	1.92	2.88	8.31	5.00	7.56
Copelata	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salpa	0.89	2.51	1.23	0.14	0.02	0.12	0.14	0.04	0.12	0.17	0.03	0.14
Doliolida	0.06	0.10	0.07	0.07	0.17	0.14	0.09	0.09	0.09	0.08	0.26	0.11
Fisheggs	0.09	0.09	0.11	0.70	0.22	0.59	0.04	0.01	0.03	0.10	0.12	0.18
Fish larvae	0.08	0.20	0.12	0.08	0.18	0.11	0.08	0.10	0.09	0.21	0.17	0.20
Otherorganisms	0.03	0.03	0.03	18.35	1.00	14.27	0.01	0.00	0.01	0.03	0.02	0.02
Mysids	0.02	0.05	0.03	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.4 Coastal and Open Ocean variability of mesozooplankton (ml.m^{-3}) in the Arabian Sea during various seasons.

Seasons	**Biomass (ml.m^{-3})**			
	Depth			
	Mixed layer (MLD)		**Thermocline**	
	Coastal	**Oceanic**	**Coastal**	**Oceanic**
SIM	0.428 ± 0.370	0.391 ± 0.212	0.253 ± 0.203	0.111 ± 0.121
SM	1.204 ± 1.829	0.653 ± 0.207	0.370 ± 0.411	0.311 ± 0.251
FIM	0.550 ± 0.414	0.255 ± 0.111	0.187 ± 0.171	0.078 ± 0.051
WM	0.212 ± 0.079	0.230 ± 0.234	0.05 ± 0.041	0.073 ± 0.071

Table 3.5 Response of the South Eastern Arabian Sea (SEAS) and North Eastern Arabian Sea (NEAS) to various environmental parameters and the resultant primary and secondary production

Parameters	Seasons	SEAS		NEAS	
		coastal	open	coastal	open
PP (mgCm^{-3} day^{-1})	SIM	4.74	2.88	2.10	1.01
	SM	43.80	5.40	3.81	4.15
	FIM	15.40	5.65	7.03	7.21
	WM	3.83	2.97	26.62	13.34
CHL(mgm^{-3})	SIM	0.22	0.13	0.27	0.09
	SM	1.10	0.26	0.23	0.21
	FIM	0.53	0.26	0.33	0.16
	WM	0.25	0.23	1.09	0.58
SST(°C)	SIM	30	29.5	28.5	28.5
	SM	26.5	28.2	28.5	29
	FIM	28.5	29	29	28.5
	WM	28.5	29	27	26
Salinity	SIM	34	35	35.5	36.5
	SM	34.8	36	35.5	36.5
	FIM	35	36.5	36.5	36.5
	WM	34	36	36	36.6
Zooplankton	SIM	0.3	0.2	0.5	0.6
	SM	5	1-1.5	1	0.5
	FIM	0.42-0.8	0.2	0.5	0.4
	WM	0.2	0.1	0.4	0.2-0.3

Table 3.6a 3 Way ANOVA for mesozooplankton biomass in the different depth layers of the coastal stations of the Arabian Sea, for comparing between seasons, between day and night, between stations in different latitudes

Source	dof	Coastal stations	
		F ratio	
		MLD	Thermocline
Seasons(A)	3	11.6598**	6.7402**
Day/Night(B)	1	0.4614^{ns}	1.1216^{ns}
Latitudes(C)	6	6.5766**	1.4946^{ns}
AB interaction	3	1.4659^{ns}	0.6666^{ns}
BC interaction	6	0.2598^{ns}	1.1850^{ns}
AC interaction	18	3.9028**	1.0920^{ns}
Error	18		

Table 3.6b 3 Way ANOVA for mesozooplankton biomass in the different depth layers oceanic stations of the Arabian Sea, for comparing between seasons, between day and night, between stations in different latitudes

Source	dof	Oceanic stations				
		F ratio				
		MLD	thermocline	300-BT	500-300	1000-500
Seasons(A)	3	3.4383*	2.6079^{b}	1.6102^{ns}	2.3964^{c}	3.065^{a}
Day/Night(B)	1	3.8583^{a}	1.0585^{ns}	0.3003^{ns}	3.4462^{b}	0.02912^{ns}
Latitudes(C)	6	1.1500^{ns}	1.8316^{ns}	0.9227^{ns}	0.8949^{ns}	0.8927^{ns}
AB interaction	3	1.8698^{ns}	2.3486^{d}	0.8317^{ns}	1.4339^{ns}	0.3123^{ns}
BC interaction	6	1.0095^{ns}	0.7163^{ns}	0.9597^{ns}	0.3755^{ns}	0.8927^{ns}
AC interaction	18	0.7345^{ns}	1.2489^{ns}	0.9494^{ns}	0.6932^{ns}	0.9540^{ns}
Error	18					
Total	55					

dof - degrees of freedom, F ratio- F statistic used for the test

Calculated F statistic is significant at (*) 5% level ($P < 0.05$), at (**) 1% level ($P < 0.01$), at (^{a}) 7%level ($P < 0.07$), at (^{b}) 8% level($P < 0.08$), at (^{c}) 10%level($P < 0.1$), at (^{d}) 11%level ($P < 0.11$),(^{ns}) not significant

* * *

Chapter - 4

MESOZOOPLANKTON OF THE BAY OF BENGAL

The Bay of Bengal, along the east coast of India, is characterized as a diluted tropical estuarine basin with oligotrophic environment. This basin is influenced by the seasonal reversal of monsoonal winds, freshwater influx and various episodic events such as formation of gyres, eddies etc. The published works documenting the biological features in the system have dealt only with the primary productivity and very few are available on mesozooplankton. However, no information is available on the response of mesozooplankton to various seasons. This chapter specifically addresses the response of mesozooplankton to various seasons and the associated biophysical processes in the BoB.

4.1 Hydrography of the Bay of Bengal

The hydrographic characteristics of the BoB are associated with prevailing monsoons and associated circulation patterns. The major physical processes that changes the hydrography and controls the biological production are, 1) Spring Intermonsoon:- Warming of surface layer (Primary heating period), Weak wind and current system (EICC), Strong thermohaline stratification, Eddies and anticyclonic gyral circulations., 2) Summer monsoon:- Strong southwesterly winds, high cloud cover and reduced solar radiation, Monsoon depressions and cyclones, Coastal upwelling, Precipitation and high river runoff, Northward moving EICC in south and southward flowing freshwater plume in north, Eddies, Barrier layer formation and intrusion of ASHSW mass, and 3) Winter monsoon:- Weak northeasterly winds and southward moving EICC, Winter convection and inversion layers, Thermohaline stratification, Eddies and Cyclonic gyral circulations. Surface meteorological observations and vertical profiles of temperature, salinity, density, nutrients, dissolved oxygen and primary productivity clearly indicated how hydrography influences the physical processes and the resulting response of the biota.

Spring intermonsoon

The observational period was characterized by southerly winds (Fig. 4.1a) with a low magnitude (1 m/s) in the central BoB and high magnitude of (6-8 m/s) along the coastal regions. Anti cyclonic winds with low magnitude of 2 m/s were noticed in the central BoB. Sea surface temperature was high (30°C) in the southern stations and low (29°C) in the 15°N transects. Low surface salinity (<32) and density (<19.5 kg/m3) were noticed at 15°N transect (Fig. 4.2a). Variation in the MLD was within 10 m, and maximum of 40 m was noticed at southern and coastal station of 15°N. Minimum MLD of 20 m was observed off 15°N. Thermocline showed a decreasing trend from southeastern BoB (>200 m) to northeastern BoB (~100 m). The distribution of DO was unique (~190 µM) except a high concentration (205µM) at off 15°N. In the nutrients, nitrate concentration was very low in (<0.02µM) in the surface layers, while phosphate showed an increasing trend from north (0.01µM) to southern (1 µM) transects (Fig. 4.5a). The oligotrophic condition prevailing in the region was evidenced by nitrate-depleted waters (Fig. 4.5a), but it was interesting to note that both phosphate (1 µM) and silicate (> 2µM) were present in surplus in the surface layers.

Vertical profiles of temperature along the coast showed warm (30°C) and thick isothermal layer (70 m) in the southern regions and that gradually decreased (29°C and 40 m respectively) towards north. Salinity and density section also showed more saline, dense waters at south and low saline waters towards north (Fig. 4.3a). Salinity and density distribution showed similar characteristics in both oceanic and coastal regions. Stability was less in the southern and central BoB, while northern stations indicated highly stable condition (Fig. 4.4a). Upsloping of isolines of temperature, salinity and density was seen in the offshore sections at 13° and 19° N. Oceanic section showed highly stable layer at a depth range of 20 to 120 m. Southern stations were more oxygenated (190-200 µM) with deep oxycline (60 m) at both coastal and oceanic stations. Nutrients (NO_3, PO_4 and SiO_4) in the coastal and oceanic stations were low at surface with a 50 m deep nitracline at south and it surfaces towards north (Fig. 4.6a &4.7a).

Summer monsoon

Southwesterly winds (Fig. 4.1b) were prevailed over the western BoB with a low magnitude (4 m/s) at southern and northern coastal stations, and high magnitude (10 m/s) at central BoB. Sea surface was warm (29°C) in the central BoB and cool (27<°C) along the southeastern coast and at 17°N; 84°E station. Fresher (<30) and low dense (<19 kg/m3) water was noticed at northern transect (Fig. 4.2b). Southeastern coast and 17°N; 84°E station were more saline (>34) in the surface layer. Coastal upwelling was the reason for the decrease of SST and increase of surface salinity along the southern coastal stations. The divergence in the cold core eddy at 17°N, 84°E decreased SST and increased the surface salinity (Fig. 4.2b). Warm (28.5°C) and less saline (<33.5) surface water extending from 13° to

17°N and from 81° to 85°E was observed in the central BoB. Shallow MLD (30 m) was noticed along the southeastern coast and 17°N; 84°E station, while deep MLD (60 m) was at central BoB. Thermocline was deep in the central BoB (>200 m) and shallow (125 m) at 17°N; 84°E station. Well oxygenated (~200 µM) surface waters were noticed at southern and central BoB with an exceptional low concentration (185µM) at 17°N; 84°E station. There was a decrease in the dissolved oxygen content (<200 µM) in the mixed layer along the southern coastal regions (Fig. 4.5b). Among the nutrients, nitrate concentration was very high (<6.02µM) at surface layer of 17°N; 84°E station that represents the cold core eddy station (Fig. 4.5b).

Vertical structure of the temperature along the coast showed warm (30°C) isothermal layer (40 m) in the northern regions and that gradually decreased (27°C) towards south(Fig. 4.3b). Low saline (31) and less dense (19.5 kg/m^3) waters were noticed in the upper layer of the northern region (Fig. 4.3b). In the oceanic section, warm (29°C) and deep (70 m) isothermal layer was noticed (Fig. 4.4b). Density stratification seen in the northern region could be due to salinity, while at south it may be controlled by temperature. Highly stable water column was noticed at both coastal and oceanic sections, in which high stability (>30) was at northern coastal station. Moderate amount of DO (190 µM) and well defined oxycline (30 m) were observed in the southern coastal station and it gradually decreased towards north from 15°N. Nutrient enrichment were observed at the upper layers of the southern coastal stations (Fig. 4.6b). DO and nutrients (Fig. 4.7b) in the oceanic stations revealed well oxygenated water column (>190 µM) with depletion in nitrate (<0.2 µM), and repletion in both phosphate (1 µM) and silicate (> 2µM).

Winter monsoon

Northeasterly winds (Fig. 4.1c) with a low magnitude (2 m/s) prevailed over northern BoB that progressively increased the magnitude (8 m/s) towards off southern BoB. The highest surface temperature (27°C) was observed off northern stations and the lowest (26°C) at 20.5°N. Surface salinity showed an increasing trend from northern (29.5) to southern (33.5) transects. Density distribution showed low dense (Fig. 4.2c) water at northern bay (19 kg/m^3) and dense water at south (22 kg/m^3). Variation in the MLD was with in 10 m; in which maximum of 40 m was noticed at southern and minimum of 20 m was at northern stations. The deep thermocline (175 m) at northern region maintained more or less uniform depth of 150 m .Distribution of DO was unique (~190 μM) except for a high concentration (205μM) off 12°N. Among the nutrients, nitrate (2.4 μM) and silicate (5.5 μM) were high in the central BoB (Fig. 4.5c).

Vertical thermal structure (Fig. 4.3c) along the coast showed thick isothermal layer (70 m) having 27°C at south and 3°C inversion layer at north. Density (20.5 kg/m^3) followed the salinity (32) structure with low dense water (19 kg/m^3) at north, where the salinity was 30 (Fig. 4.3c). Oceanic section (Fig. 4.4c) showed comparatively cool (26°C), saline (33.5) and dense (22 kg/m^3) waters at south than northern stations (28°C, 32, 21 kg/m^3 respectively). Both coastal and oceanic stations possessed highly stable water column with a maximum stability at 30 to 40 m depth. Moderately high oxygen (190μM) and nutrients (NO_3, PO_4 and SiO_4) were observed along (Fig. 4.6b) coastal (~2.5, 0.5, and 5μM, respectively) and oceanic (~2, 0.4, and 5 μM respectively) stations (Fig. 4.7c).

4.2 Biological characteristics

4.2.1 Chlorophyll *a* and primary production

Spring intermonsoon

During SIM, Chlorophyll *a* at the surface varied from 0.1 to 0.27 mg m^{-3} (Table 4.1). High chlorophyll *a* (Avg. 0.27 mg m^{-3}) and primary production (8.53 mg C m^{-3} d^{-1}) were observed along the coast and southern BoB. During this period, average column chlorophyll *a* (17.07 mg m^{-2}) was higher in the southern coastal stations. Column primary production was slightly higher in the northern transects (302-323 $mgCm^{-2}day^{-1}$) compared to the south (218-234 $mgCm^{-2}day^{-1}$).

Summer monsoon

During summer monsoon Chlorophyll *a* at the surface varied from 0.13 to 0.38 mg m^{-3} (Table 4.1). Low chlorophyll (<0.2 mg m^{-3}) and primary production (<200 mg C m^{-2} d-^{1}) were noticed in the central BoB with an exceptional high at off 15 and 17°N. Column primary production was high (322.90 mg C m^{-2} d-^{1}) in the coastal regions of southern BoB (Table 4.1).

During this season, three different and spatially varying physical processes were identified in the upper 300 m of the BoB. An anticyclonic warm gyre offshore in the southern Bay (13° 30' to15° 30'N and 82° to 88°E); a cyclonic eddy in the northern Bay (17°30'; 84°E); and an upwelling region adjacent to the southern coast (11°30' 15°30'N).The chlorophyll a and primary production rate were varying in these processes. The Average surface chlorophyll *a* (Fig. 4.15a) and primary production (Fig. 4.15b) in the warm gyre, cyclonic eddy and in the upwelling region were 0.12 mg m^{-3}, 0.14 mg m^{-3} and 0.25 mg m^{-3} and 2.55 mg C m^{-3} day^{-1}, 4.2 mg C m^{-3} day^{-1}, and 9.23 mg C m^{-3} day^{-1}respectively. Compared to the warm gyre and cyclonic eddy, the upwelling region showed high surface chlorophyll *a* and primary production (Fig. 4.15b)

Winter monsoon

During this season, surface chlorophyll *a* at the coastal regions varied from 0.09 mg m^{-3} to 0.58 mgm^{-3} and that of oceanic were 0.12mgm^{-3} to 0.16 mgm^{-3} The average coastal surface and column primary production in the southern regions were 13.38 mg $Cm^{-3}d^{-1}$ and 341.63 $mgCm^{-2}d^{-1}$ and the corresponding oceanic regions was 5.62 mg C $m^{-3}d^{-1}$ and 344.82 mg C m^{-2} d^{-1} (Table 4.1). The average coastal surface and column primary production in the northern regions were 3.73 mg $Cm^{-3}d^{-1}$ and 161.82 $mgCm^{-2}d^{-1}$ and the corresponding oceanic regions was 2.36 mg $Cm^{-3}d^{-1}$ and 117.18 $mgCm^{-2}d^{-1}$ (Table 4.1)

4.2.2 Vertical distribution of mesozooplankton and its seasonal changes

Spring intermonsoon

The mesozooplankton biomass during this season was comparatively lower than the other seasons. The average biomass in the mixed layer was 0.16 ml. m^{-3} (Table 4.2). The highest biomass (0.44 ml.m^{-3}) in the mixed layer was recorded in the offshore station along the 19°N, 85E transect (Fig. 4.8a). In the thermocline region the average biomass was 0.04ml.m^{-3} and it ranged between 0.02 to 0.15 ml.m^{-3} The highest biomass of 0.15 ml. m^{-3} in the thermocline layer was noticed in the offshore station at the 19°N, 89°E and coastal station of 15°N, 80°E (Fig. 4.9a). The biomass was drastically decreased toward the deeper layers and the variation was insignificant in between seasons (Fig. 4.11, 4.12 & Table 4.1)

The total abundance of mesozooplankton in the mixed layer average was 4319±178 ind.m^{-3}. About 21 mesozooplankton taxa were identified during this season. Copepod contributed the major share both in the mixed layer (80%) and thermocline layer (78%). Other dominant groups were chaetognaths (9.91%), salps (2%), decapods (1.82%), copelates (1.14%), ostracods (1.41%) and polychaetes (1.11%) (Table 4.4). In the thermocline layer the abundance of chaetognaths (11.89%), euphausiids (1.06%),ostracods, (2.30%), siphonophores (2.07%) were higher than the mixed layer.

Summer monsoon

The average biomass during this season in the upper 1000 m water column was 0.56 $ml.m^{-3}$ (Fig. 4.8b) and in the mixed layer was 0.45 $ml.m^{-3}$(Table 4.2). Mesozooplankton biomass in the mixed layer ranged between 2.27 $ml.m^{-3}$ (13.5 N; 85°E) and 0.054 $ml.m^{-3}$ (13.5°N; 80.5° E). The coastal station along the 13°N transect recorded the highest biomass of 2.31 $ml.m^{-3}$ In the thermocline layer the average biomass was 0.122 $ml.m^{-3}$ and the highest was recorded at the southern coastal regions of 11°N -15°N (Fig. 4.9b).

Total abundance of mesozooplankton in the mixed layer for this season was 31710 $ind.m^{-3}$ Among the mesozooplankton groups, copepods contributed to 67% of the total abundance followed by copelates (6.27%), ostracods (5.98%), and chaetognaths (3.8%) in the mixed layer. Fish larvae (1.04%) and eggs (12.02%) were higher during this season. In the thermocline layer the copepod percentage (Table 4.4) was 65% and ostracod was (21%) the second dominant group.

Three different and spatially varying physical processes observed in the upper 300 m of the BoB. Viz. anticyclonic warm gyre, cyclonic eddy, and upwelling have influenced the zooplankton standing stock. Mesozooplankton biovolume (Fig. 4.16) in the mixed layer of the warm gyre averaged 0.14 ml m^{-3}, which was much lower than in either the cyclonic eddy (0.67 ml. m^{-3}) or the upwelling region (1.12 ml. m^{-3}). Foraminifera, chaetognaths, copelates, siphonophores, fish larvae, and medusae, were the most prevalent taxa present in the warm gyre. The population density (Table 4.5) of foraminifera in the MLD of the warm gyre (4.72 ind. m^{-3}) was higher than in either the cyclonic eddy (negligible) or the upwelling region (0.23 ind. m^{-3}), indicating a higher (r >0.5) affinity of this group to the warm waters. The mesozooplankton biovolume (Fig. 4.16) in the MLD of the eddy averaged 0.67 ml m^{-3}, and the numerical density of the dominant groups of zooplankton in this region varied: Copepoda (1036 ind. m^{-3}), Ostracoda (13 ind. m^{-3}), Decapoda (21 ind. m^{-3}), euphausiids (6 ind. m^{-3}), Chaetognatha (32 ind. m^{-3}), fish eggs (216 ind. m^{-3}) and fish larvae (1 ind. m^{-3}) (Table 4.5). The highest mesozooplankton biovolume, (Fig. 4.16) averaging 1.12 ml.m^{-3} in the mixed layer of the upwelling region was observed (Fig. 4.16). The dominant taxa in the upwelling region were copepoda (1697 ind.m^{-3}), copelata (291 ind.m^{-3}), ostracoda (42 ind.m^{-3}), chaetognatha (37 ind.m^{-3}), doliolids (33 ind.m^{-3}), euphausiids (27 ind.m^{-3}), decapoda (22 ind.m^{-3}), polychaeta (16 ind.m^{-3}), pteropods (14 ind.m^{-3}), siphonophores (10 ind.m^{-3}), medusae (6 ind.m^{-3}), salps (1 ind.m^{-3}), gastropoda (1 ind.m^{-3}) and amphipoda (1 ind.m^{-3}) in decreasing order of abundance. Fish eggs (617 ind.m^{-3}) and larvae (2 ind.m^{-3}) were more abundant in the upwelling region than in either the warm gyre or the cyclonic eddy (Table 4.5).

Winter monsoon

During this season, the average mesozooplankton biomass in the upper 1000 m water column was 0.34 ml.m^{-3} and in the mixed layer it was 0.22 ml.m^{-3} (Table 4.2). The spatial distributions of mesozooplankton showed that the northern transect especially the northern offshore waters sustaineed high biomass (range between 0.2 to 0.4 ml.m^{-3}) with maximum of 0.45 ml.m^{-3} at 17°N, 86°E (Fig. 4.8c). In the thermocline layer the average mesozooplankton biomass noticed was 0.06 ml.m^{-3} (Fig. 4.9c& Table 4.2).

The composition of mesozooplankton in the mixed layer and thermocline are given in Table 4.4. The mean abundance of mesozooplankton during this season was very low (319 ind.m^{-3}) Copepod contributed the maximum (77%) followed by chaetognatha (6.21%) and copelata (4.2%) in the mixed layer. The contribution of copepod in the thermocline layer was higher (89.5%) than that of the MLD (Table 4.4). Chaetognatha (6.46%) was the second dominant group in thermocline. The other dominant groups in the mixed layer and thermocline layer were euphausiids, decapods, polychaetes and ostracods.

4.2.3 Coastal and oceanic variability of mesozooplankton distribution

Coastal stations

The maximum biomass of zooplankton occurred along the coastal regions during all the seasons. The highest biomass in the MLD and thermocline of the coastal regions of the BoB was during summer monsoon (Table 4.3). The MLD and thermocline biomass of coastal regions, during summer monsoon was at an average of 0.79± 0.75ml.m^{-3} and 0.18 ±0.19 ml.m^{-3} respectively. Mixed layer and thermocline layer of the southern latitudes possessed high biomass of zooplankton especially at 13°N during summer monsoon (Fig. 4.13). During summer monsoon both, MLD and thermocline possessed high zooplankton biomass at the southern coastal regions of 13°N. The spatial variation between the north and south coastal regions were not that much apparent during winter monsoon and spring inter monsoon.

The copepod abundance in the MLD was high in the northern and southern coastal regions during inter monsoon spring with a percentage contribution of 81.7% and 82.8% respectively, where as this taxa tended to decreased during summer monsoon and winter monsoon. The other taxa found in the MLD during summer monsoon were copelata, chaetognatha, ostracods etc. The composition of zooplankton taxa were differed in the coastal and oceanic regions of southern and northern BoB (Fig. 4.14).

Oceanic stations

Maximum biomass of mesozooplankton in the mixed layer of the oceanic region of the BoB was observed during summer monsoon with an average of 0.36±0.55 $ml.m^{-3}$ followed by winter monsoon (0.24±0.10 $ml.m^{-3}$). In the MLD, the offshore BoB possessed least biomass during Spring inter monsoon (Table 4.3). No obvious difference was seen between the southern and northern latitudes of BoB during different seasons except a rise in biomass was seen at the 19°N during summer monsoon. In the thermocline strata, a gradual increase in biomass was observed from the south to northern latitudes (Fig. 4.13).

In offshore regions also the copepods were the numerically abundant group both in MLD and thermocline layers (Fig. 4.14). Their percentage contribution was maximum during winter monsoon (77%). In the thermocline, the copepod contribution during spring inter monsoon was drastically decreased (70%). Ostracods were the second dominant group and their contribution was high in the MLD of summer monsoon (20%). In the thermocline chaetognaths comprised about 14% during spring intermonsoon. During winter monsoon there was an increase in abundance of pyrosoma in the offshore of BoB. Considering the north and south regions of the BoB, there was a significant variation of the zooplankton composition during various seasons (Fig. 4.14).

4.3 Statistical Analysis

3 way Analysis of Variance (3 way ANOVA)

3 way ANOVA was applied for comparing the mesozooplankton biomass, between seasons, between stations in different latitudes, and between day and night in the mixed layer and thermocline layer of the coastal and oceanic stations of the BoB (Table 4.6a & 4.6b).

In the mixed layer of the coastal stations, season wise differences were significant at 1% level ($F(3, 12) = 6.7674$, $P < 0.01$) where as the station wise difference were at a low level of significance ($F(4, 12) = 2.7417$, $P<0.08$). Season station interaction ($F(12, 12) = 2.9342$, $P<0.05$) (Table 4.6a) was high in the MLD of the coastal stations.

Mesozooplankton varied significantly with respect to seasons ($F(1, 12) = 3.007$, $P < 0.07$) with respect to day and night ($F(1, 12) = 2.9015$, $P<0.11$) and with respect to latitudes, $F(4, 12)=2.7372$, $P<0.08$) in the mixed layer of oceanic stations, with high dependency for stations on seasons ($F(12, 12) = 1.7732$, $P <.17$). Seasonal differences in the mesozooplankton biomass of the thermocline layer was high ($F(3,12) = 3.78661$, $P<0.05$) in the oceanic stations together with station dependency on seasons ($F(12,12)=1.7391$, $P < 0.18$) (Table 4.6b). In 300-BT layer in the open ocean mesozooplankton biomass varied concretely with respect to seasons ($F(3, 12) = 2.0803$, $P < 0.16$) but at a lower level of confidence at 84%. In 300-500 depth stratum in open ocean seasonal (F(3, 12) = 4.9210, P<0.05) as well as latitudinal differences (F(4, 12) = 2.6916, P < 0.08) were high (Table 4.6b).

4.4 Discussion

The Bay of Bengal is a Semi-enclosed basin with immense freshwater influx forced with semi-annual reversing monsoon resulted air-sea interaction, complex circulation pattern and spatio-temporal variability in the hydrographic structure of the ecosystem. Seasonally varying freshwater influx from the rivers brings considerable amount of sediments, may probably contributes nutrients to the upper layers of the BoB. This may alter the hydro-chemical properties of the BoB and expected to respond these factors on a seasonal scale (Sardesai *et al.*, 2007). Earlier studies on productivity concluded that most of the time in a year system behaves as oligotrophic. The possible reasons for oligotrophy are unavailability of nutrients in the photic zone due to thick barrier layer, heavy cloud cover and turbid water column due to sediment flux that reduce the solar penetration (Radhakrishna *et al.*, 1978 a &b; Qasim, 1977; Gomes *et al.*, 2000; Prasannakumar *et al.*, 2002; Madhupratap *et al.*, 2003). Limited studies have been carried out to elucidate the biological aspects of the BoB (Madhupratap *et al.*, 2003; Prasannakumar *et al.*, 2007; Paul *et al.*, 2008; Fernandes *et al.*, 2008). Most of these studies have concentrated only on the primary production and bacterioplankton and hence a comprehensive approach is needed to explain the mesozooplankton production (secondary production). Results from the present study discussed here are the physical forcing on hydro-chemical structure of the BoB during different seasons and their relation to the mesozooplankton abundance and distribution.

Warm sea surface (29.5°C) was almost uniform from south to north during the primary heating period (Spring inter monsoon). High saline waters observed along the coast and low saline at oceanic stations can be explained by the pole ward flowing EICC that pushes low saline water away from the coast and advect high saline Arabian Sea water to north (Sanil kumar *et al.,* 1997). Anti-cyclonic flow pattern of the prevailing winds during SIM was the major driving force of large anti-cyclonic gyre (ACG). Clock- wise and anti-clock wise circulation of EICC at the offshore and inshore causes the formation of ACG and cold core eddies. Upsloping of isolines of temperature, salinity and density seen at 13° and 19° N in the oceanic sections were due to the existence of cold core eddy. Because of the strong stratified surface layer, these eddies were not able to reach surface. This gyral circulation collapses with the intensification of southwest monsoon (Babu *et al.*, 2003). Thus warm and low saline water in the oceanic region of the BoB become highly stable by thermo-haline stratification. This is the major reason for thick barrier layer formation and shallow mixed layer during this period. Weak winds were not strong enough to erode the water column beneath the barrier layer to surface, and therefore nutrients in the photic zone remained low, leading to oligotrophy. Deep nitracline (0.2 µM) was seen at 50 m depth due to thermo- haline stratification. Entrainment of these nutrients to the photic zone or penetration of solar radiation to this deep nitracline may be the reason for the deep chlorophyll maximum. Warm anti-cylonic gyral circulation deepen the isothermal layer thereby increasing the barrier layer thickness that prevents mixing and thus intensify the oligotrophic condition, while cylonic eddies push nutrient rich sub surface water to photic zone and shift oligotrophic to eutrophic system. During this season chlorophyll *a* at the surface was very low compared to other two seasons; this could be mostly due to the extended stratification in the surface layers. Gomes *et al* (2000) reported low concentrations of chlorophyll in the offshore regions of BoB.

During SIM, the zooplankton biomass was considerably less in the entire BoB. In highly stratified water, the primary production and chlorophyll were very low, which adversely affect the growth of mesozooplankton. Most of the phytoplankton may be smaller sized during this season. Marshall (1973) reported larger copepods and other zooplanktons are unable to consume the smaller sized phytoplankton efficiently, which in turn reduces the abundance of mesozooplankton. The reduction in zooplankton may also be due to the warmer and more stratified waters. The general reduction of mesozooplankton may be due to increasing temperature (30.6°C) during this season. With increasing temperature, respiration and general metabolic demands increase disproportionally and lower the physiological tolerance to the physical environment. During this season the dominant component in the mesozooplankton was copepods (>80%) in the mixed and in the thermocline layers (Fig. 4.14 & Table 4.3) of both coastal and oceanic regions. This increase was not correlated with chlorophyll standing crop, suggesting that a food resource other than phytoplankton may be responsible for the onset of copepod production prior to the spring bloom. Heterotrophic microplankton as an alternative food source, and advection of copepods from the stratified region, are proposed as possible explanations for copepod abundance before the summer peak in primary production. The high percentage contribution of copepods may be due to the presence of small sized copepods. Rakesh *et al.*, 2006 reported that small-sized copepods like Oithona sp., Paracalanus sp., *Clausocalanus* and Acrocalanus gibber were found during SIM. Small-sized copepods as those dominating during early spring, have a limited capacity to consume significant amounts of phytoplankton, because of their small guts compared to those of larger copepods. Their high numbers do not compensate for these limitations. However, these small copepods are known to consume significant amounts of microplankton (e.g., protozoa and crustacean plankton) in order to fulfil their metabolic requirements (Batten *et al.*, 2001). Evidence that *Clausocalanus* spp. can rely not only on phytoplankton, but also on an animal diet, has been reported by Kleppel *et al.* (1988) .*Clausocalanus furcatus* can persist in oligotrophic waters, where the trophic energy is mainly channelled through the microbial and protozooplankton components of the pelagic food webs. Spring intermonsoon is a period when stratified, well-oxygenated and nutrient-deplete surface layers favor the proliferation of cynobacteria and play a significant role in the pelagic food web. Jyothibabu *et al.*, (2005) reported that ciliates were high in the BoB during inter monsoon spring followed by summer and winter. Chaetognaths and salps formed a distinct group during SIM; their high abundance was also concordant with the results of Rakesh *et al.*, (2006). Within carnivorous zooplankton, chaetognaths play a major role both in their biomass contribution and also in their impact on zooplankton communities as one of the main predators of copepods (Pearre, 1980; Stuart and Verheye, 1991). Salps are filter feeders that collect food particles using mucous nets (Alldredge and Madin, 1982). These mucous nets can become clogged when filtering very high concentrations of particles (Harbisonan d Gilmer, 1976), which may exclude salps from areas of unusually high particle concentration such as (Harbison et al., 1986) high Chl *a* concentrations and primary production. Tunicate growth rates are known to be temperature dependent when other factors are constant (King, 1982;

Paffenhofer, 1976). Thus, salps living in warmer waters may grow faster than salps found in cooler waters. Towards the deeper layers, the mesozooplankton biomass was decreasing sharply (Table 4.2). This sharp decrease in zooplankton abundance with depth is well known phenomenon (Longhurst, 1980; Angel and Baker, 1982).

Cool sea surface (29°C) was observed in the coastal region of the southern BoB during summer monsoon. Cooling (27.5°C) along the coast of southwestern BoB can be explained through the coastal upwelling. LaFond (1957), Murty and Varadachari (1968), Shetye et al. (1991) and Rao (2002) have reported upwelling along the coasts of the BoB during summer monsoon. Strong (8 m/s) south westerly winds were prevailing over the region was favorable for the upwelling that pushed surface water to offshore and brought cool nutrient rich sub surface water to surface and enriched the biological production Bhavanarayana *et al.*, (1957); Udayavarma *et al.*, 1959). Madhu *et al.* (2002) have reported primary production and chlorophyll *a* distribution in the upwelling regions of the southwestern BoB during summer monsoon. High saline water (34) seen along the coast is the evidence for the coastal upwelling. Coastal upwelling in the northern Bay of Bengal is suppressed by the southward moving low salinity plume, although favorable winds force local upwelling south of 17.5°N. Circulation pattern and hydrographic structure showed the existence of a cold core eddy that upwelled sub surface cool nutrient rich water to surface layer by breaking strong thermo-haline stratification. Observation suggests that deep water may be brought to the surface in this region by vertical mixing also, as suggested by Banse (1990).

During summer monsoon, chl *a* and the primary production at the surface were relatively higher than that of other seasons. Gomes *et al* (2000) reported nearly fivefold increase in offshore chl *a* value compared to the intermonsoon spring. Three concomitant processes (anti-cyclonic warm gyre in the south, coastal upwelling and a cyclonic eddy in the north) were found to react differentially to the biological production in the Bay of Bengal during summer monsoon (Muraleedharan *et al.*, 2007). Compared to the warm gyre and cyclonic eddy, an enhanced biological activity was observed in the upwelling zone by a switch over to new production. The warm gyre remains oligotrophic, but the cyclonic eddy, despite having relatively more nutrients than the upwelled waters, continue to be relatively less productive due to its time lag in transforming in to eutrophic system.

The highest biomass of mesozooplankton was obtained during summer monsoon. Biomass values from the southern coastal stations were higher than the northern coastal stations. Distribution trends of zooplankton biomass closely matched phytoplankton biomass and production. Madhupratap et al., (2003) stated that the coastal waters of BoB sustain high phytoplankton biomass during summer upwelling. In the present study, copepods were the most abundant group during the season, but compared to other seasons, their percentage contribution was less during this season. Chaetognaths, fish eggs and fish larvae were the other dominant constituents of the zooplankton population, much similar to other upwelling areas. Madhupratap *et al,* (1999), reported that during upwelling, herbivorous and carnivorous zooplankton occurred in large numbers while carnivorous were found low numbers during other seasons (Madhupratap and Haridas, 1986). A study conducted during the summer monsoon in BoB (Achuthankutty et al, 1980) showed a southward shift in abundance of zooplankton south of Madras associated with a mild upwelling. Fresh water influx from the rivers maximizes during summer (Shi *et al.*, 2002), which is in accordance with the observed difference in salinity, high dissolved (Sengupta et al., 1977) and particulate organic carbon, may provide favorable trophic conditions for filter feeding zooplankton groups such as oikopleura, doliolids and appendicularians which are known to feed on small sized particles (Turner *et al.*, 1988). Abundance of these groups was much higher in summer. Dominance of relatively large-sized phytoplankton cells and colonies (mostly diatoms), typical of upwelling areas, may explain the relatively higher impact on medium and large copepods biomass when compared to small copepods in the study area.

During winter monsoon, sea surface was warm at central and southern Bay of Bengal (27.5°C). High surface salinity (33.5) was noticed at south and low (29.5) at northern stations. (1988) reported stratification at deeper depths of northern BoB was caused by freshwater influx. Barrier layer thickness decreased from northern to southern station, and salinity stratification played a major role for the distribution of barrier layer. Deep MLD was noticed with high saline waters at southern stations and shallow MLD with less saline water at northern stations. Dry and cool north easterly winds with low magnitude at north (2 m/s) and increased magnitude (8 m/s) at southern stations were observed. These features are the peculiarities of winter monsoon (Hastenrath and Lamb, 1979). The atmospheric conditions prevailing over the Bay was favorable for winter convection, but winds were not strong enough to churn up water column (over come strong thermo-haline stratification) or cooling the sea surface to trigger winter convection. This resulted in a high temperature layer below the sea surface known as thermal inversion (Pankajakshan *et al.*, 2002). Thermal inversion, the prominent feature in BoB during winter, was more pronounced (4.3 °C) in the north, while in south it was relatively less. Many authors have reported the phenomenon of thermal inversion in the BoB (Shetye *et al.,* 1996; Pankajakshan *et al.,* 2002). Shetye *et al.* (1996) suggested that the process of inversion in the BoB starts in the north during summer monsoon and accelerates with the onset of the northeast monsoon. Winter cooling did not lead to convective mixing and enrichment of upper layers in the BoB due to intense stratification by the fresh water cap (Banse, 1984; Prasanna Kumar and Prasad, 1996; Madhupratap *et al.,* 1996; Jyothibabu *et al.,* 2004). This may be the reason for reduced chlorophyll *a* and primary production in the northern BoB compared to southern BoB. Madhu *et al.*, (2006) reported that southwestern BoB (11°N and15°N) has relatively high phytoplankton standing stock and production, compared to the northwest and diatoms were dominated during this season.

The total abundance of zooplankton during winter was comparatively lower than that of summer monsoon and intermonsoon spring. Strong stratification during the winter monsoon prevented vertical mixing resulting in oligotrophy, and low primary and secondary production in the study area. Copepod was the major zooplankton component during the winter monsoon and are the most abundant multicelled organisms on earth (Mauchline, 1998). Thus, they quickly respond to the changing environmental factors in any ecosystem. Chaetognaths were the second dominant group which may be due to the presence of copepods, since it forms the diet of chaetognaths (Reeve, 1980; Pearre, 1980; Øresland, 1987). High abundance of copepods seemed to coincide with high chlorophyll *a* concentrations, which may indicate increased growth and survival in high productive areas. In the present observation, the abundance of copepod was high in the southern coastal and oceanic stations than the northern regions. During winter monsoon there was an increase in abundance of pyrosoma in the offshore of BoB. Size-fractionated feeding experiments showed a consistent preferential uptake of algal cells larger than 10 μm in diameter, compared to those smaller than this size (Perissinotto et al., 2007). In the South Atlantic study, Drits *et al.* (1992) had identified, centric diatoms, silico-flagellates and even fragments of small crustaceans, apart from the coccolithophores in the faecal pellets of *Pyrosoma atlanticum*. The occurrence of high numbers of ciliate protozoans was observed in interstitial areas of freshly dissected colonies. Jyothibabu (2005) has reported low abundance of ciliate protozoans in the BoB during winter monsoon compared to other seasons.

The statistical results indicated that the seasonal difference of mesozooplankton biomass was significant in the mixed layer of the coastal stations of BoB than in the open ocean stations. The latitudinal variation of mesozooplankton biomass was also significant in the coastal stations. All these seasonal variations can be attributed to the observed variability in the hydrographical parameters and the associated primary productivity patterns in the BoB.

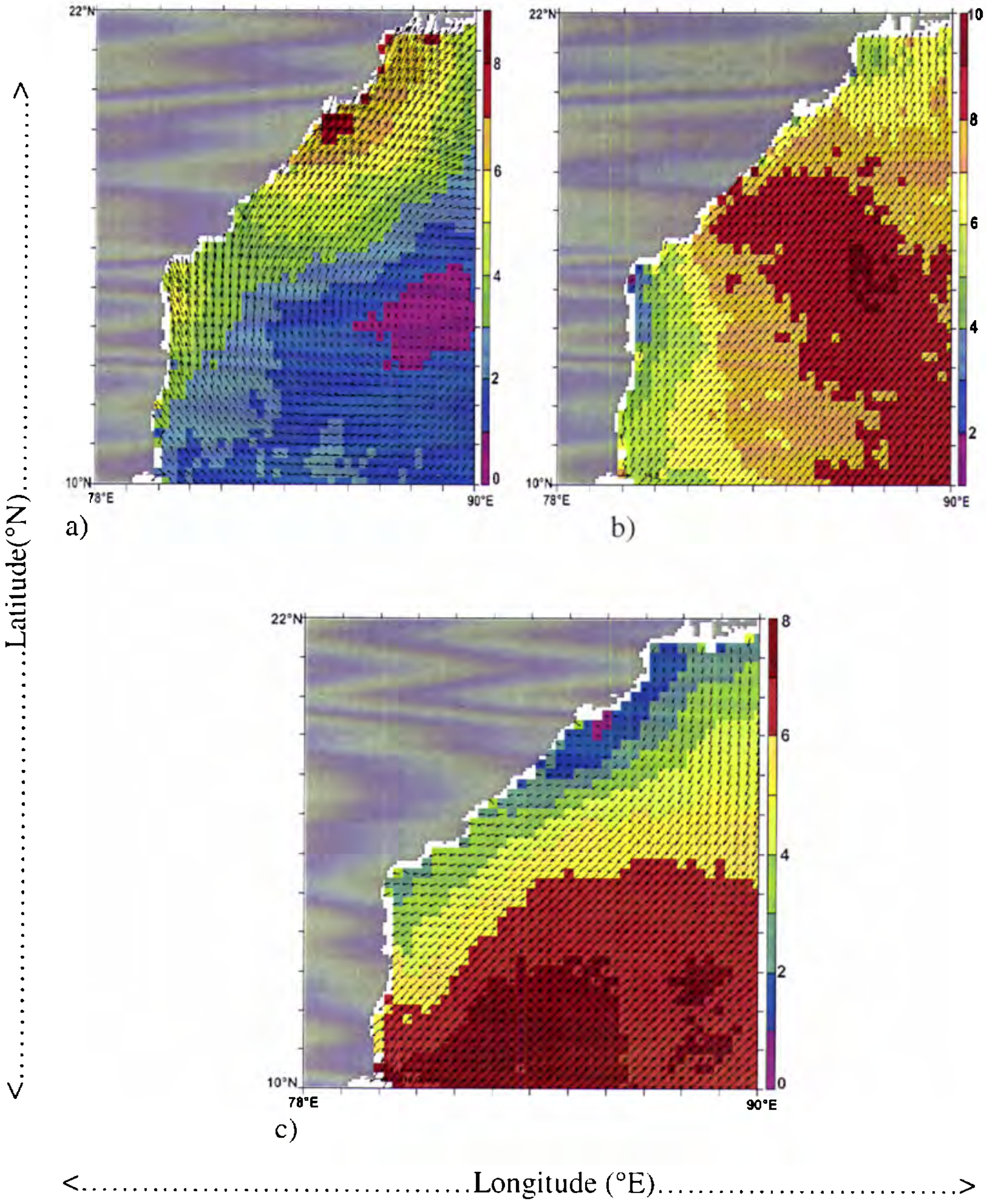


Fig. 4.1 Wind Pattern in the BoB during a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

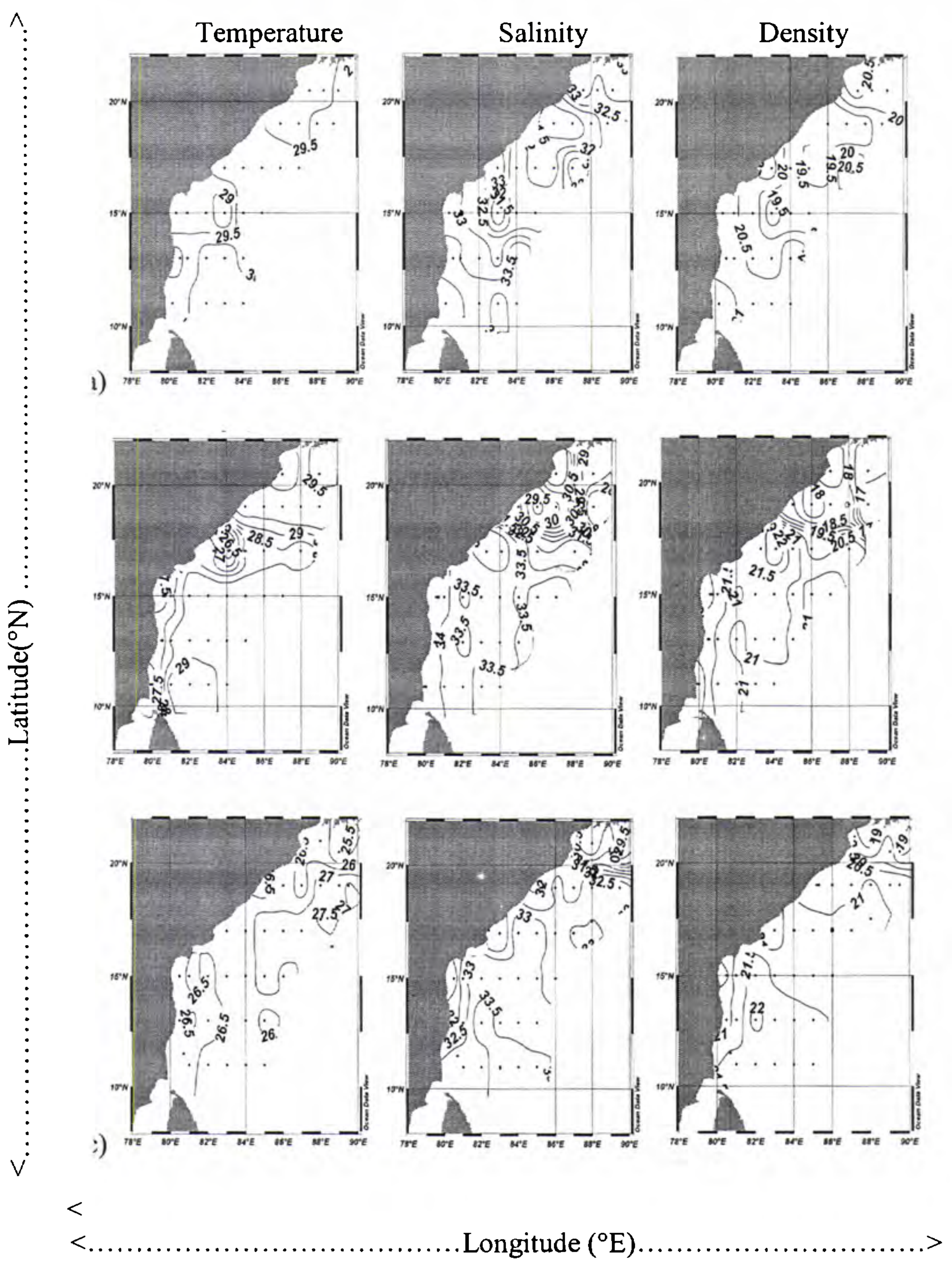


Fig. 4.2 Spatial distribution of Surface Temperature (°C), Salinity and Density in the Arabian Sea during a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

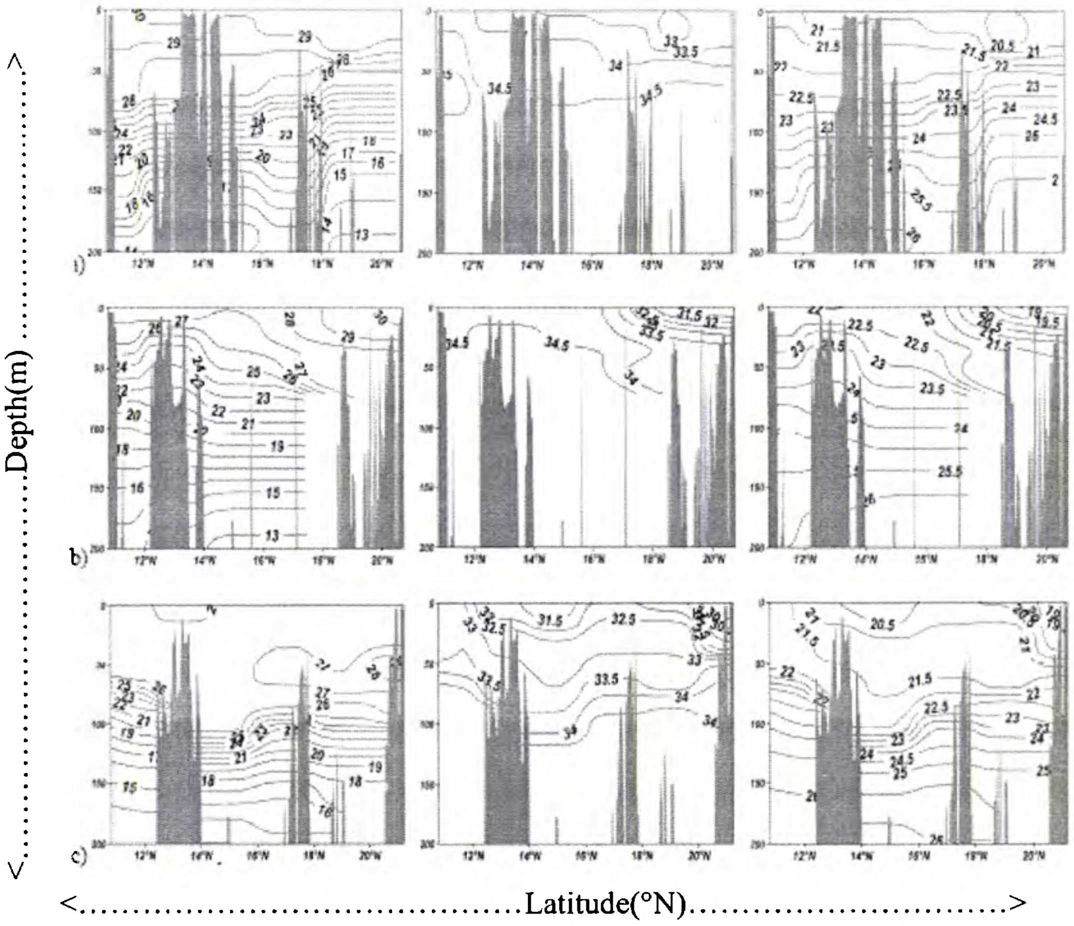


Fig. 4.3 Vertical distribution of Surface Temperature (°C), Salinity and Density in the coastal stations of the Bay of Bengal during a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

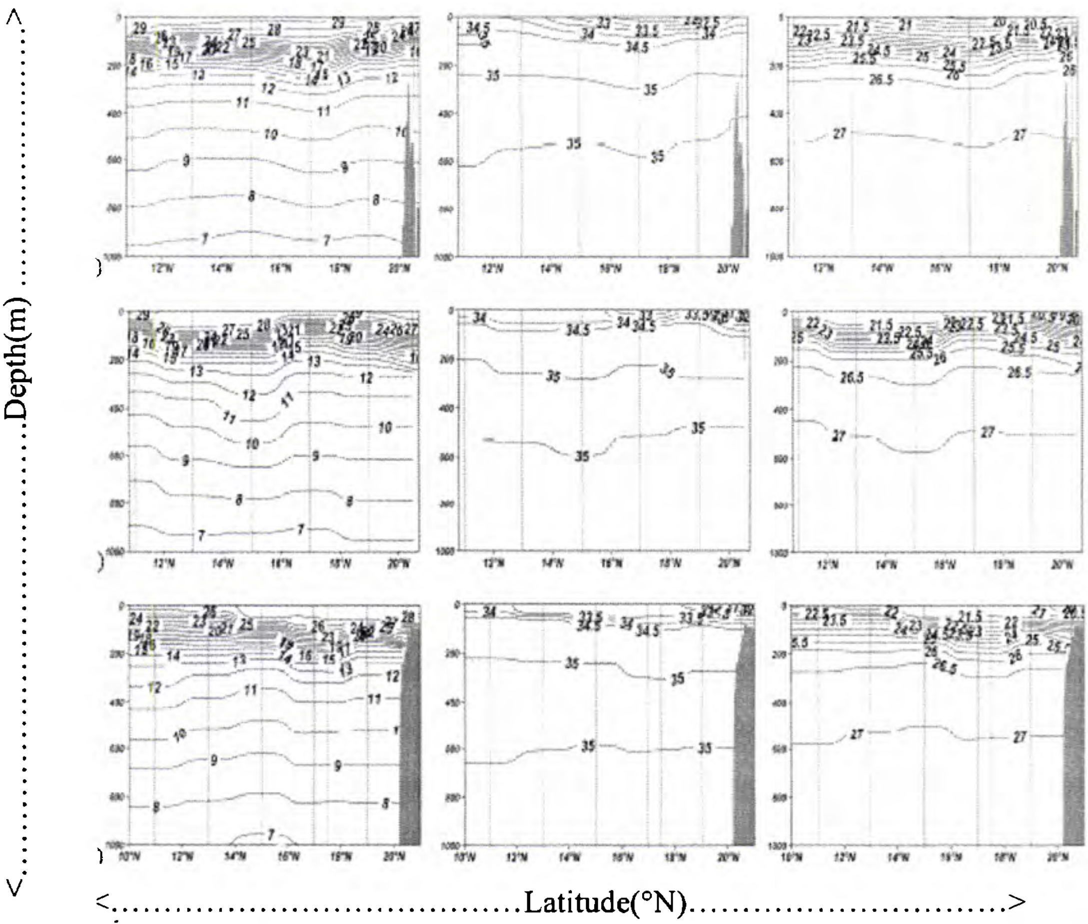


Fig. 4.4 Vertical distribution of Surface Temperature (°C), Salinity and Density in the oceanic stations of the Bay of Bengal during a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

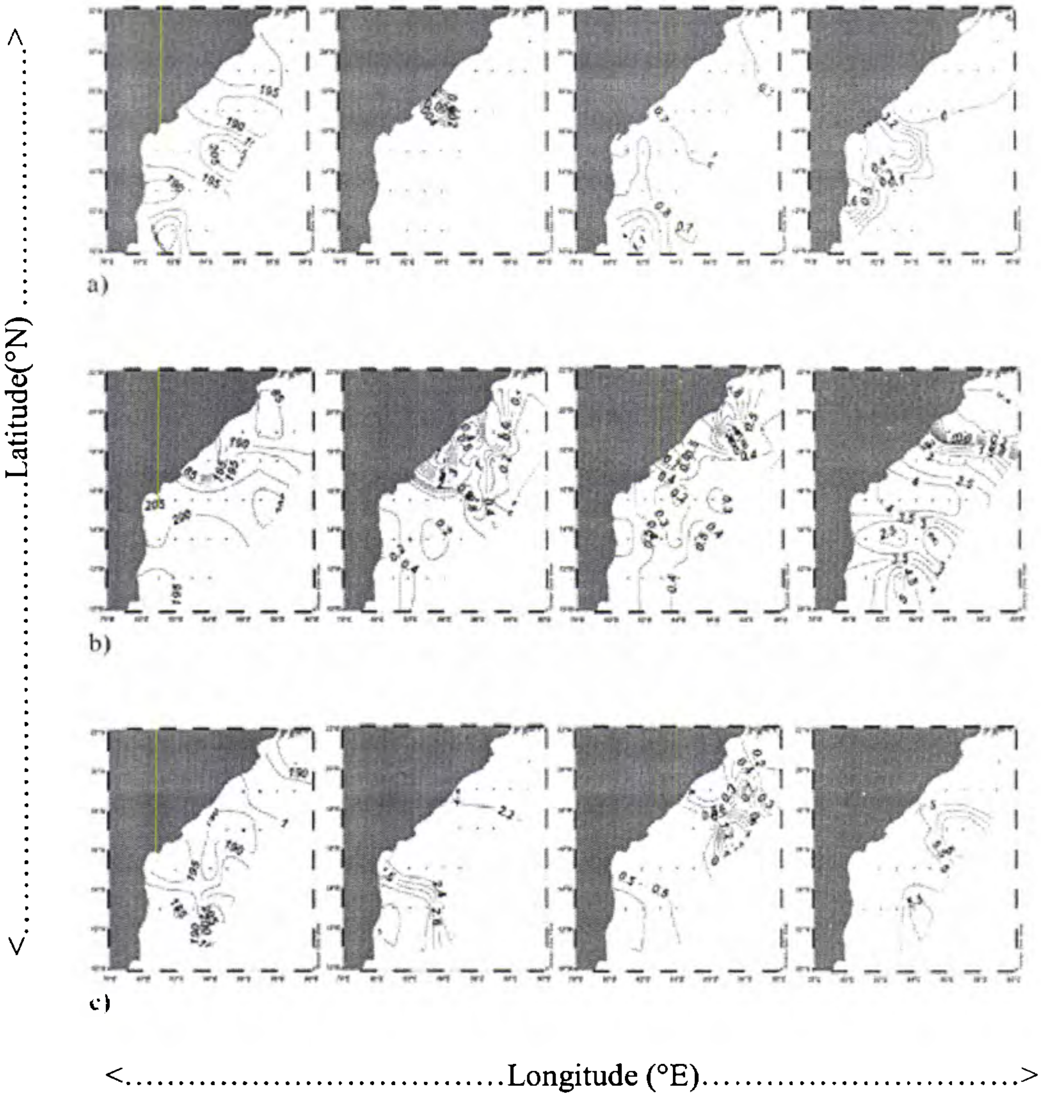


Fig. 4.5 Surface distribution of dissolved oxygen (μM), Nitrate (μM), Phosphate (μM) and Silicate (μM) in the Bay of Bengal during a) Spring inter monsoon b) Summer monsoon c) Winter monsoon.

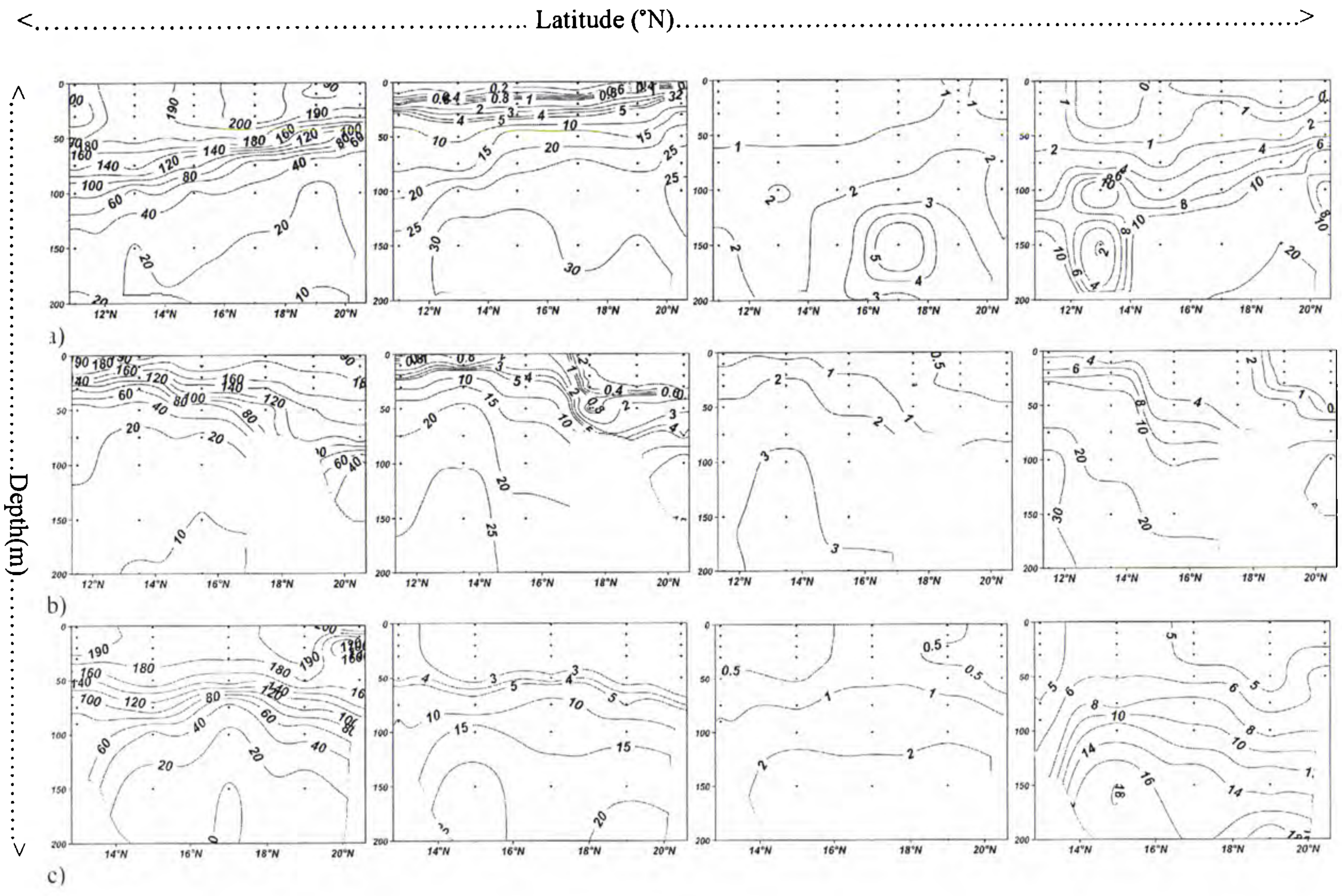


Fig. 4.6 Vertical distribution of a)Dissolved oxygen b)Nitrate c)Phosphate and d) Silicate in the Coastal stations of the Bay of Bengal during a) Spring inter monsoon b) Summer monsoon c) Winter monsoon

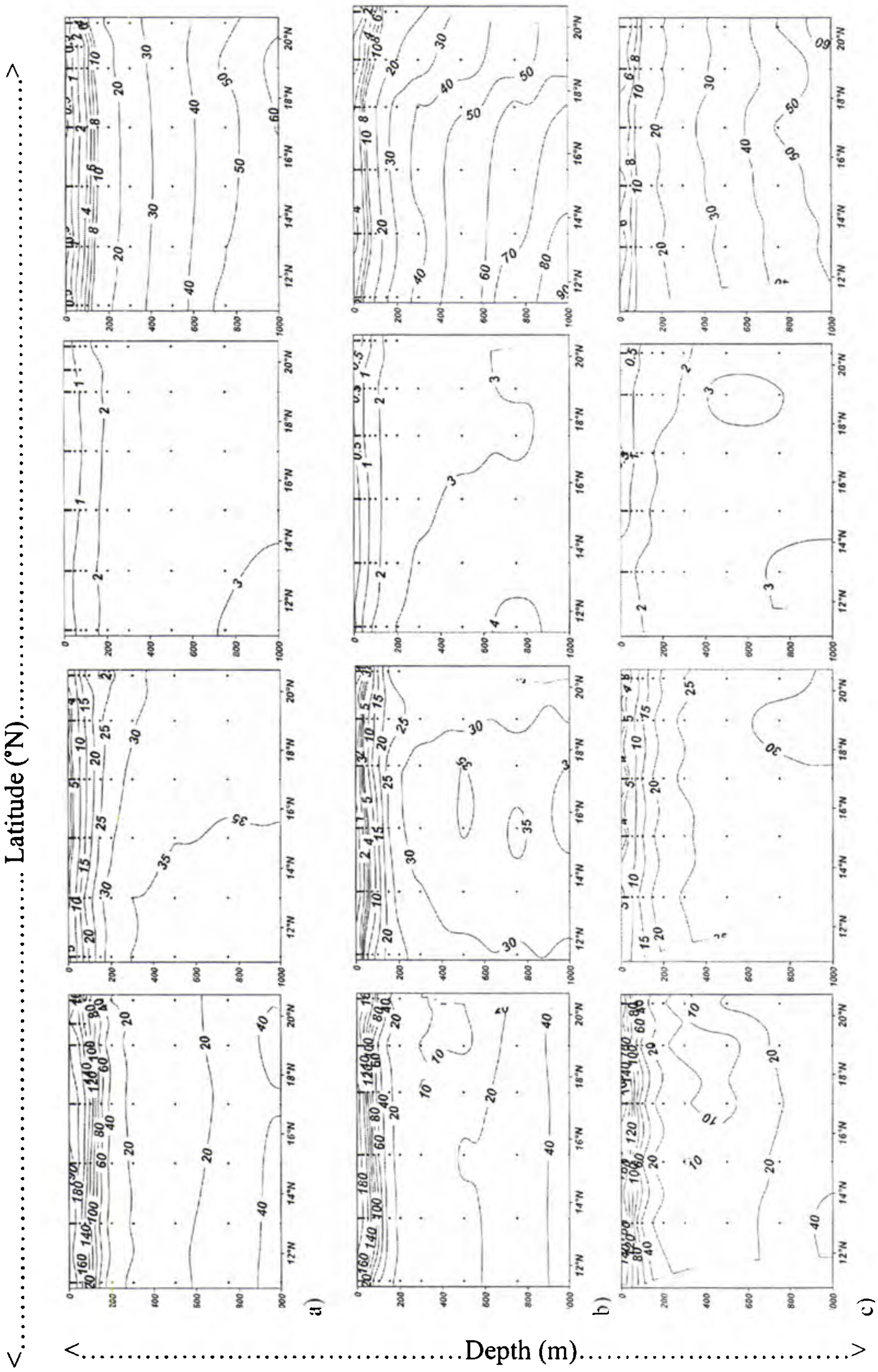


Fig. 4.7 Vertical distribution of a)Dissolved oxygen b)Nitrate c)Phosphate and d) Silicate in the Oceanic stations of the Bay of Bengal during a) Spring inter monsoon b) Summer monsoon c) Winter monsoon

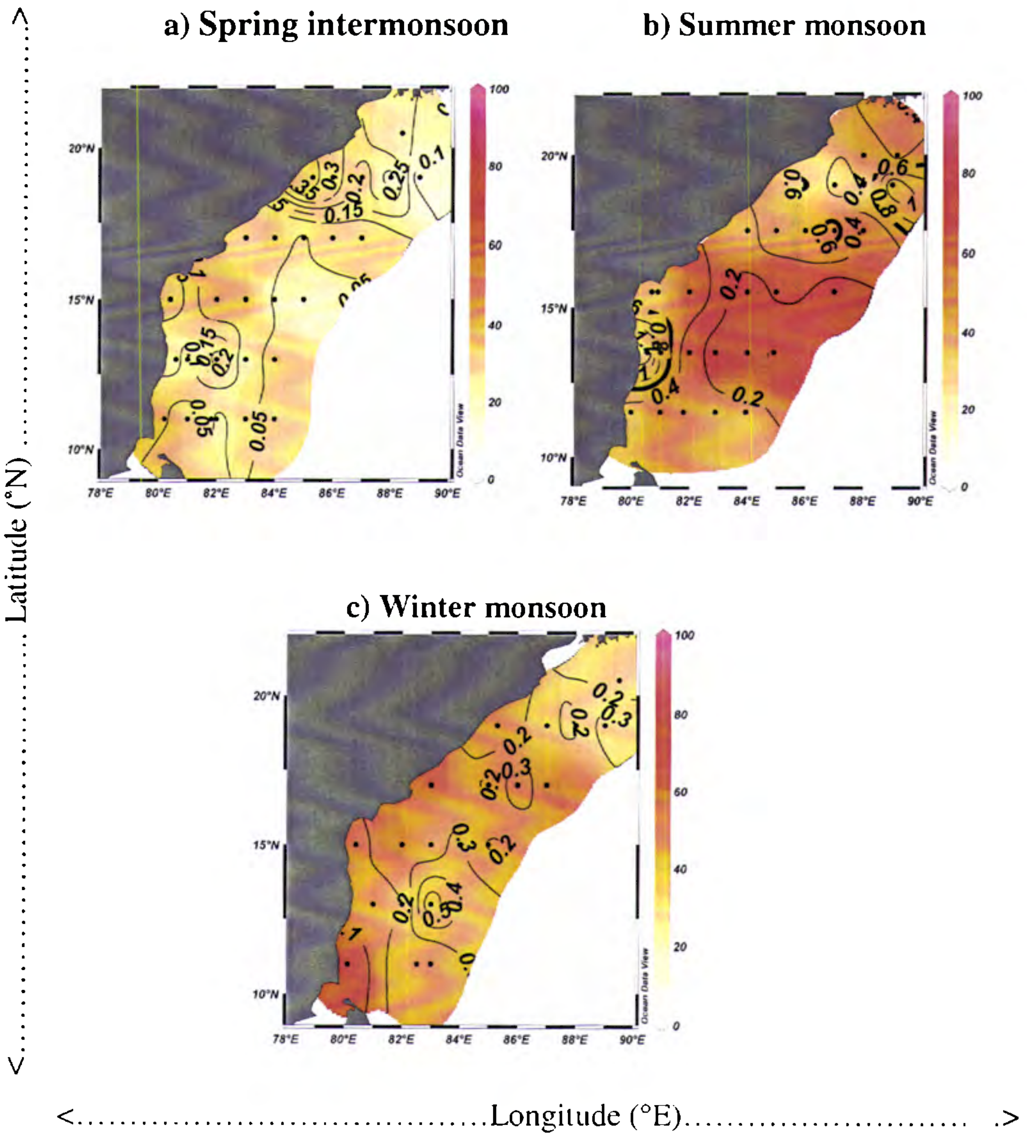
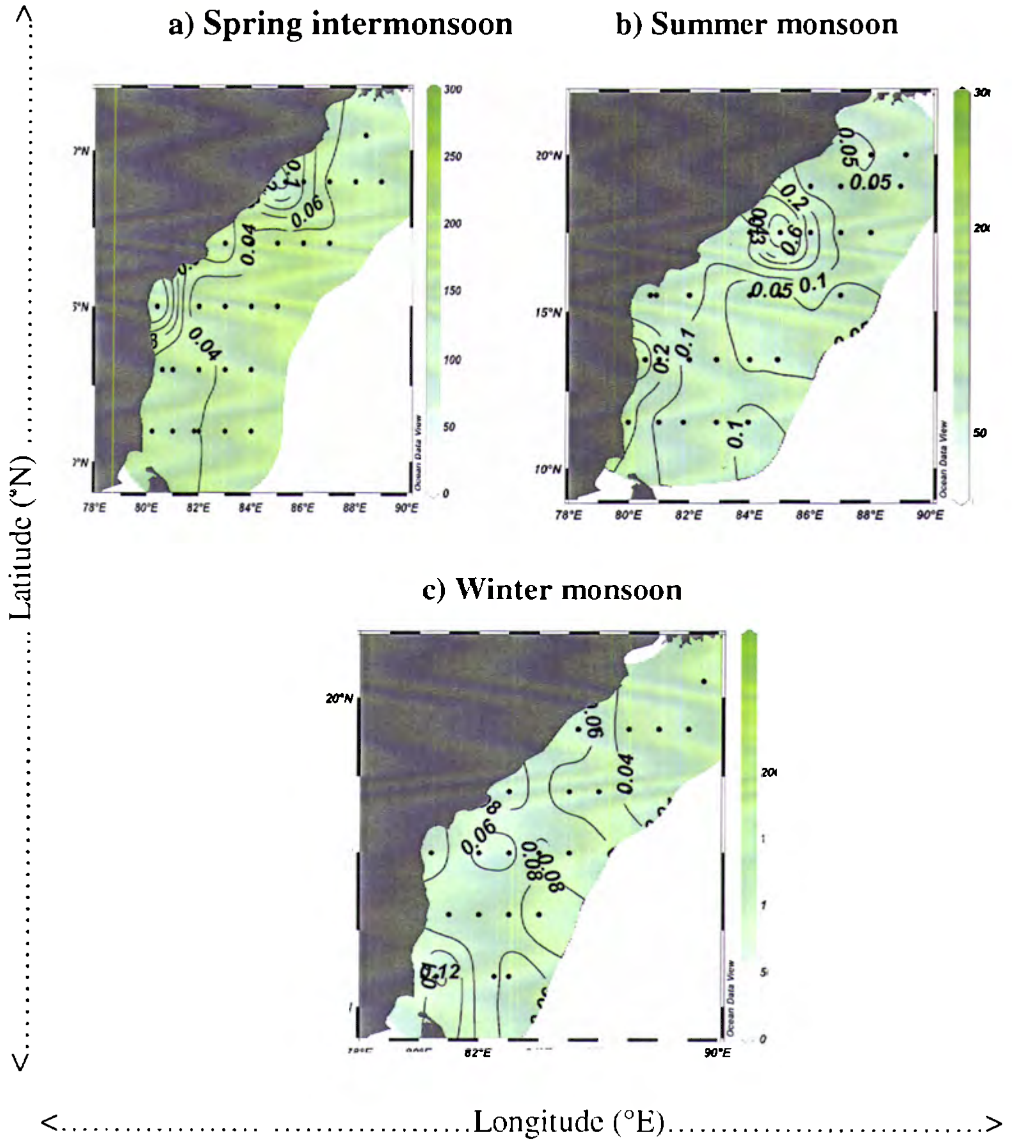


Fig. 4.8 Mesozooplankton standing crop (ml.m^{-3}) in the mixed layer of the Bay of Bengal during different Seasons. Biomass contours are superimposed on the mixed layer depth (m).


a) Spring intermonsoon

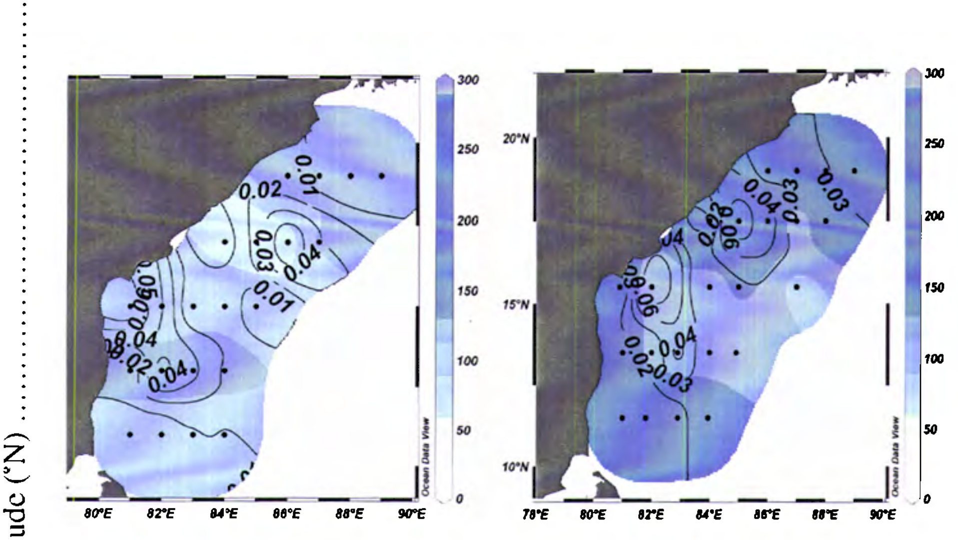
b) Summer monsoon

c) Winter monsoon

Fig.4.9 Mesozooplankton standing crop (ml.m^{-3}) in the Thermocline layer of the Bay of Bengal during different Seasons. Biomass contours are superimposed on the Thermocline depth (m).

a) Spring intermonsoon

b) Summer monsoon



c) Winter monsoon

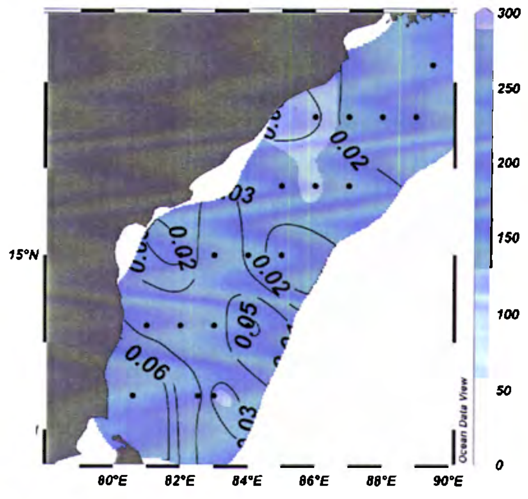


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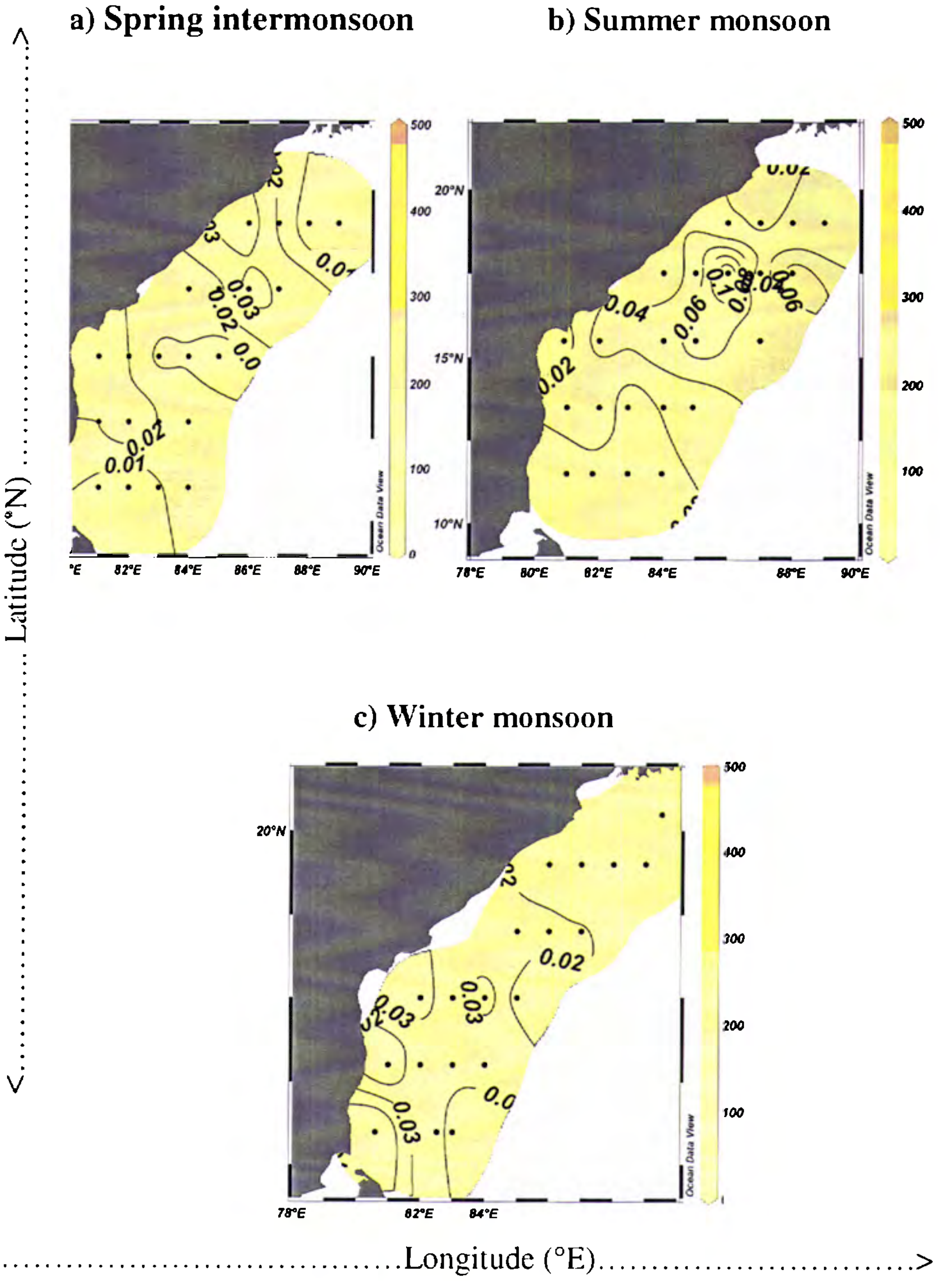
Fig. 4.10 Mesozooplankton standing crop (ml.m^{-3}) in the 300-thermocline depth of the Bay of Bengal during different Seasons.



a) Spring intermonsoon

b) Summer monsoon

c) Winter monsoon

Fig. 4.11 Mesozooplankton standing crop (ml.m^{-3}) in the 500-300 depth of the Bay of Bengal during different Seasons.

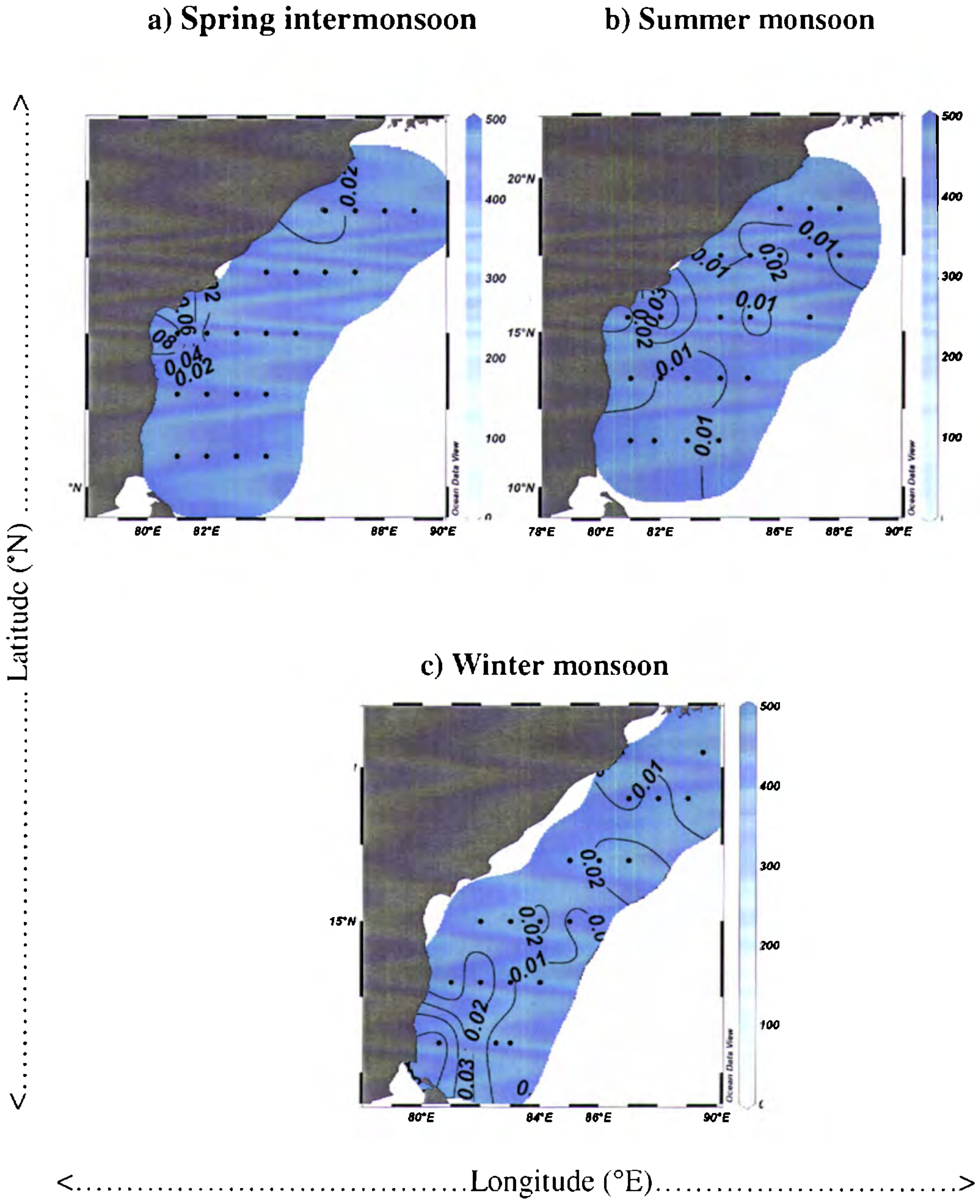


Fig. 4.12 Mesozooplankton standing crop (ml.m^{-3}) in the 1000-500m depth of the Bay of Bengal during different Seasons.

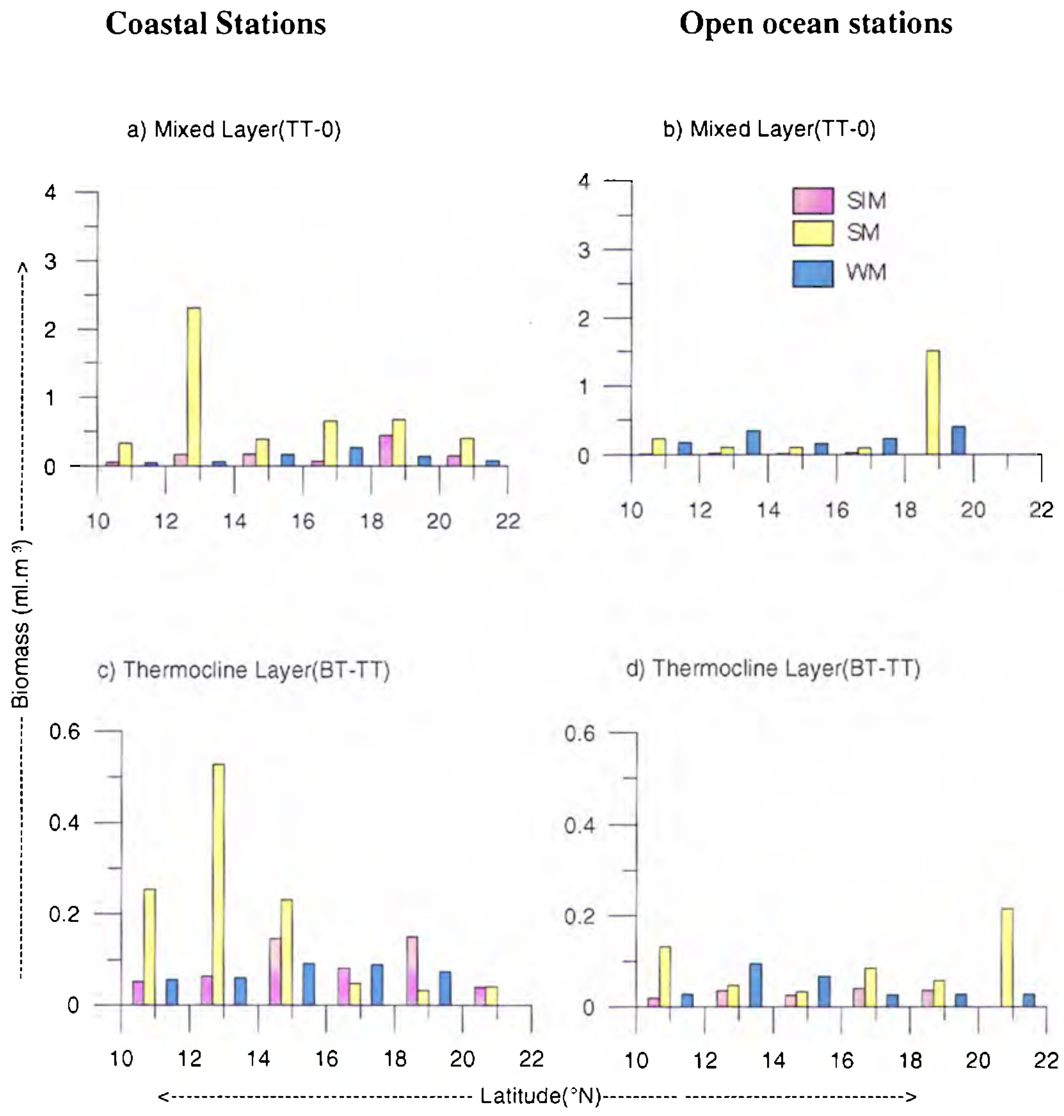


Fig. 4.13 Mesozooplankton Biomass (ml.m^{-3}) in the coastal and open ocean stations of Bay of Bengal during different seasons in the mixed layer and Thermocline layer

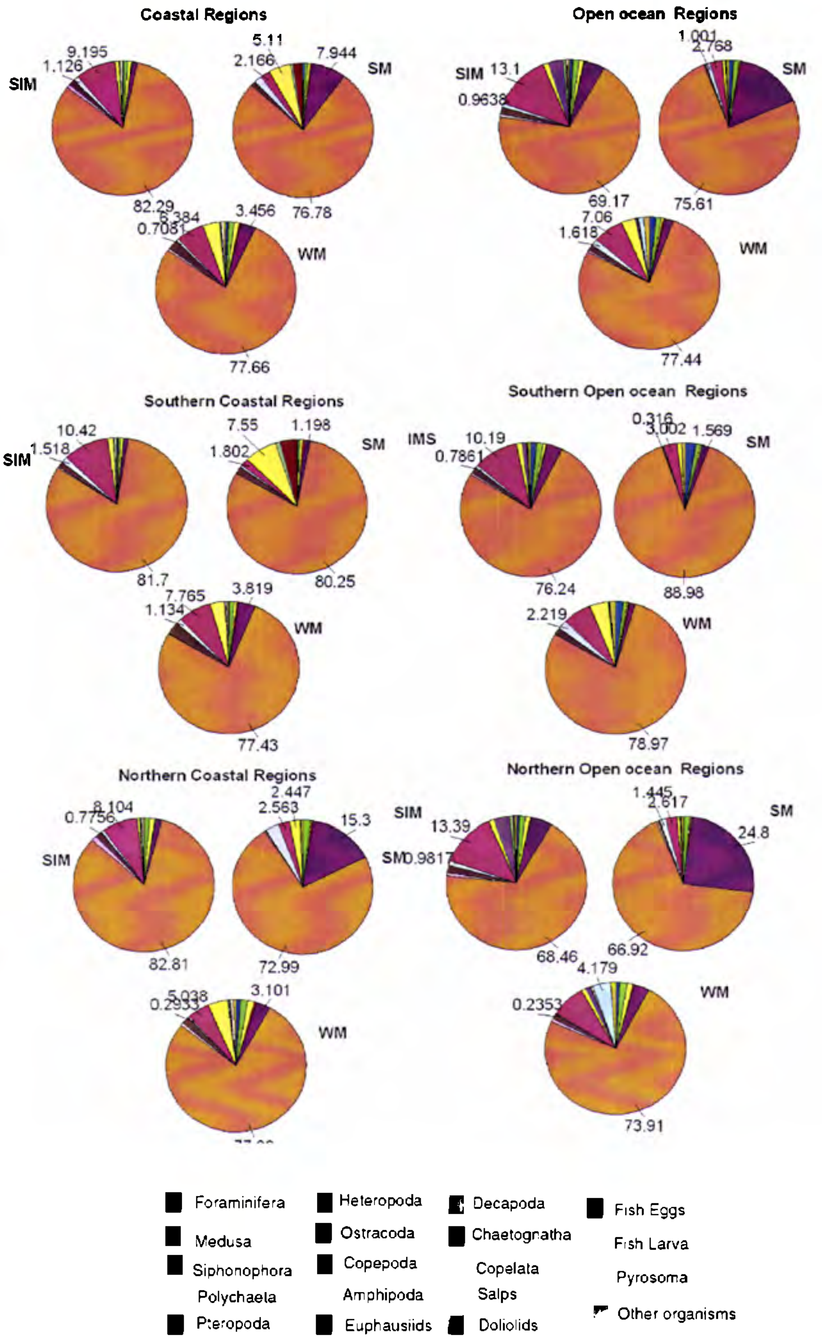


Fig. 4.14 Percentage contribution of Mesozooplankton in the coastal regions (upper 200m) and Open ocean regions(upper 1000m) of the Bay of Bengal during different Seasons

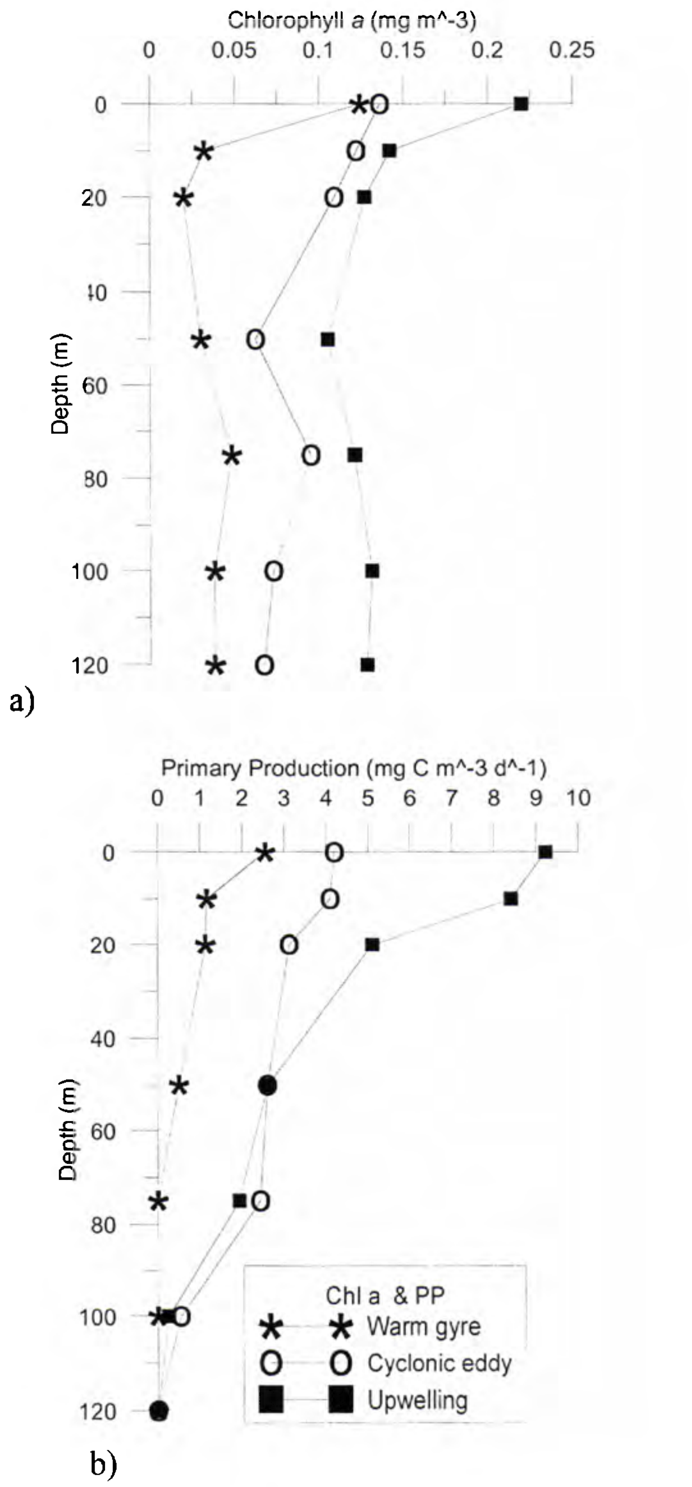


Fig. 4.15 Average vertical profiles of a) chlorophyll *a* concentration (mg m^{-3}) and b) primary productivity (mg C m^{-3} day^{-1}) in the warm gyre, cyclonic eddy and upwelling regions.

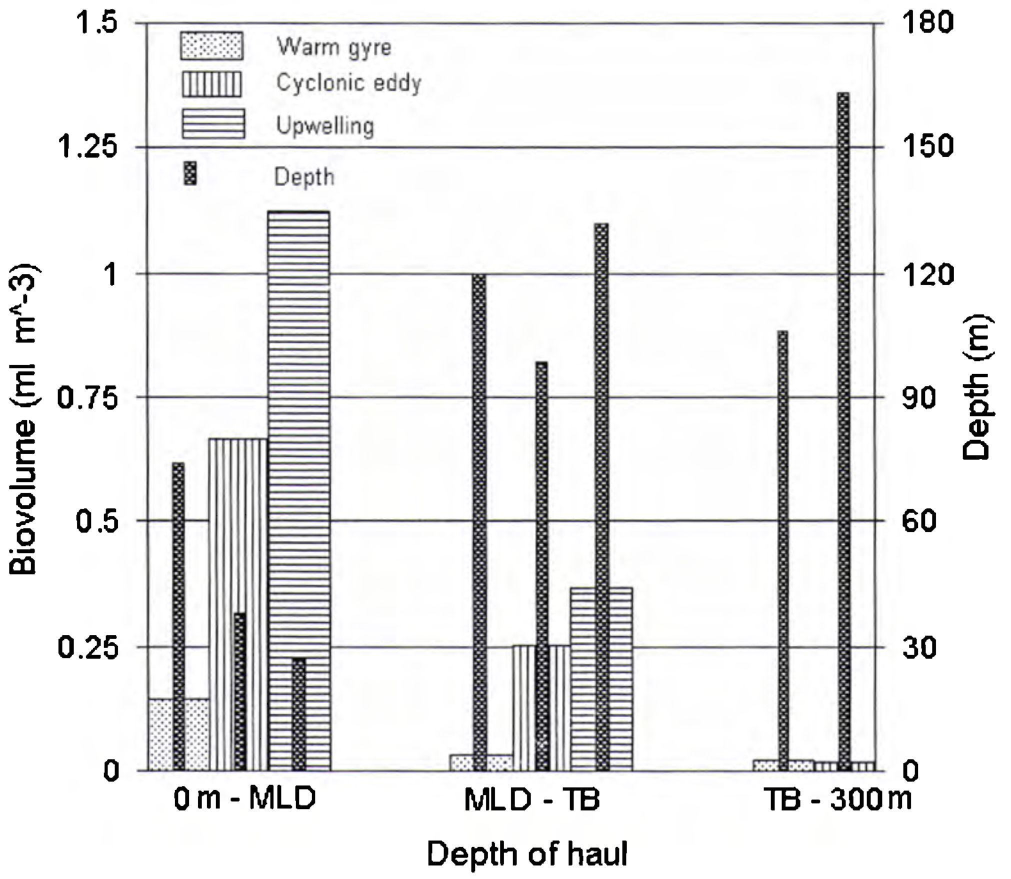


Fig. 4.16 Average mesozooplankton biovolume (ml m^{-3}) in the mixed layer, thermocline (TB) and TB to 300 m of the warm gyre, cyclonic eddy and upwelling region. The secondary axis shows the average distance (m) hauled by the MPN net according to the above criteria.

Table 4.1 Chlorophyll a (mg m^{-3}) and primary production (mgCm^{-3} d^{-1})in the Bay of Bengal during various seasons. 'C' and 'O' represents the coastal and oceanic stations.

Seasons			**Bay of Bengal**			
			Surface Chl *a* (mgm^{-3})	**Column Chl *a*** (mgm^{-2})	**Surface Primary production** (mgCm^{-3} day^{-1})	**Column primary production** (mgC$m^{-2}$$day^{-1}$)
Spring	North	C	0.12	13.48	2.94	323.45
		O	0.19	11.13	5.12	302.50
	South	C	0.19	17.07	6.55	218.15
		O	0.27	15.28	8.53	234.97
Summer	North	C	0.14	10.09	4.20	268.00
		O	0.16	9.16	9.12	175.00
	South	C	0.13	13.51	7.38	322.90
		O	0.16	7.19	3.12	117.15
Winter	North	C	0.09	9.52	3.73	161.82
		O	0.12	9.15	2.36	117.18
	South	C	0.58	16.24	13.38	341.63
		O	0.16	13.86	5.62	344.82

Table 4.2 Average Mesozooplankton biomass in the different depth layers of the Bay of Bengal during various seasons.

Seasons	**Biovolume (ml.m^{-3})**		
	Spring inter monsoon	**Summer monsoon**	**Winter monsoon**
Mixed Layer	0.16	0.45	0.22
Thermocline	0.04	0.12	0.06
300-BT	0.02	0.02	0.03
500-300	0.02	0.03	0.02
1000-500	0.01	0.01	0.02
Upper 1000m	0.33	0.56	0.34

Table 4.3 Distribution of mesozooplankton in the Inshore and Offshore regions of the Bay of Bengal.

Seasons	**Biomass (ml.m^{-3})**			
	Depth			
	Mixed layer (MLD)		**Thermocline (BT-TT)**	
	Coastal	**Oceanic**	**Coastal**	**Oceanic**
SIM	0.18 ±0.15	0.04 ±0.05	0.088± 0.04	0.03± 0.008
SM	0.79± 0.75	0.369 ±0.55	0.18 ±0.19	0.09± 0.06
WM	0.12 ±0.08	0.24± 0.10	0.07 ± 0.016	0.04± 0.02

Table.4.4 Different mesozooplankton taxa (%) at the mixed layer, thermocline layer and the upper1000m water column in the Bay of Bengal during different seasons.

Seasons	IntermonsoonSpring			Summer monsoon			Inter monsoon fall			Wintermonsoon		
Mesozooplankton Taxa (%)	MLD	BT-TT	Upper 1000m	MLD	BT-TT	Upper 1000m	MLD	BT-TT	Upper 1000m	MLD	BT-TT	Upper 1000m
Foraminifera	0.37	0.87	0.62	0.19	0.40	0.27	0.25	0.55	0.34	0.77	1.81	0.99
Medusa	0.02	0.04	0.03	0.16	0.26	0.18	0.08	0.20	0.11	0.07	0.12	0.08
Siphonophore	0.95	2.07	1.35	0.87	0.55	0.79	0.46	0.41	0.44	1.40	1.57	1.35
Anthozoa	0.00	0.00	0.17	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ctenophora	0.00	0.00	0.00	0.03	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Polychaeta	1.01	0.70	0.86	0.49	0.60	0.50	0.19	0.35	0.21	0.77	0.86	0.74
Pteropoda	0.34	0.12	0.25	0.37	0.11	0.32	0.23	0.09	0.19	0.45	0.26	0.38
Heteropoda	0.11	0.06	0.09	0.01	0.01	0.01	0.07	0.03	0.06	0.13	0.05	0.11
Gastropoda	0.18	0.11	0.23	0.10	0.05	0.09	0.09	0.22	0.12	0.59	0.40	0.52
Cephalopoda	0.03	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
Cladocera	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ostracoda	1.41	2.30	1.93	5.98	21.50	8.58	0.60	3.36	1.25	2.29	2.95	2.59
Copepoda	79.65	77.79	78.54	67.08	65.44	67.49	91.21	84.79	89.08	77.30	80.51	78.60
Isopoda	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Amphipoda	1.03	0.65	0.85	0.21	0.13	0.19	0.14	0.43	0.19	0.54	0.36	0.47
Euphausiid	0.81	1.06	0.90	0.95	0.78	0.92	0.79	1.00	0.87	1.70	1.24	1.55
Decapoda	1.82	0.72	1.39	1.19	0.54	1.06	0.72	0.52	0.65	0.95	0.75	0.87
Stomatopoda	0.01	0.01	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.05	0.14	0.06
Halobates	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.12
Chaetognatha	9.91	11.89	9.90	2.97	3.18	2.97	2.27	5.67	2.88	6.21	6.46	5.91
Copelata	1.14	0.68	0.93	6.27	0.74	5.14	2.31	1.44	2.02	4.20	1.27	3.33
Pyrosoma	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.07	1.00	0.30	0.92
Salpa	0.58	0.43	0.58	0.10	0.04	0.09	0.13	0.07	0.11	0.21	0.37	0.22
Doliolida	0.07	0.08	0.08	0.48	0.17	0.43	0.16	0.15	0.18	0.16	0.10	0.14
Fisheggs	0.28	0.12	0.23	12.23	5.25	10.64	0.09	0.13	0.10	0.39	0.05	0.31
Fish larva	0.25	0.32	1.04	0.11	0.10	0.10	0.03	0.09	0.05	0.35	0.31	0.32
Otherorganisms	0.00	0.01	0.00	0.03	0.03	0.03	0.00	0.04	0.89	0.09	0.10	0.24
Mysids	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.04	0.00	0.00	0.00

Table 4.5 General taxonomic composition of mesozooplankton and its mean abundance (ind. m^{-3}) in the upper 300 m of three different physical systems: the warm gyre, the cyclonic eddy and coastal upwelling

Meso-Zooplankton Groups	Warm gyre			Cyclonic eddy			Upwelling	
	MLD 0-74 m	Thermocline 74-194 m	194-300 m	MLD 0-38 m	Thermocline 38-137 m	137-300 m	MLD 0-27 m	Thermocline 27-159 m
Foraminifera	4.72	1.88	0.52	0.00	0.36	0.00	0.23	0.00
Medusa	0.28	0.01	0.01	2.94	3.27	0.26	5.75	0.44
Siphonophora	6.53	0.41	0.06	5.94	0.26	0.01	9.73	1.30
Anthozoa	0.00	0.00	0.00	0.03	0.01	0.00	0.23	0.00
Ctenophora	0.00	0.00	0.00	0.00	4.02	0.00	0.56	0.01
Polychaeta	1.71	0.67	0.05	5.42	3.15	0.00	15.53	3.48
Pteropoda	0.87	0.09	0.03	1.91	0.01	0.01	14.30	0.42
Heteropoda	0.04	0.00	0.00	0.04	0.00	0.00	0.00	0.01
Gastropoda	0.34	0.10	0.06	0.03	0.00	0.00	1.23	0.83
Cephalopoda	0.09	0.01	0.00	0.00	0.00	0.00	0.17	0.04
Ostracoda	13.09	5.57	1.99	13.63	2.45	0.04	42.11	14.85
Copepoda	310.10	64.83	20.51	1036	99.22	4.46	1697.33	446.99
Isopoda	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00
Amphipoda	0.97	0.13	0.00	0.99	0.07	0.01	0.90	0.08
Euphausiid	1.43	0.74	0.73	6.29	0.38	0.02	26.55	12.28
Decapoda	1.63	0.65	0.14	21.57	0.19	0.02	21.25	3.51
Stomatopod	0.00	0.00	0.00	0.52	0.00	0.00	0.88	0.06
Chaetognatha	24.47	3.83	0.53	32.42	1.00	0.02	37.96	15.25
Copelata	10.75	0.10	0.00	16.38	0.00	0.00	291.14	6.30
Salpa	0.08	0.02	0.00	0.04	0.01	0.00	1.39	0.27
Doliolida	0.40	0.12	0.60	0.55	0.21	0.00	33.19	3.31
Fish egg	0.07	0.01	0.01	216.99	0.00	0.00	616.84	21.02
Fish larva	0.65	0.09	0.00	2.03	0.01	0.02	3.97	0.30

Table 4.6a 3 Way ANOVA for mesozooplankton biomass in the mixed layer and Thermocline layer of the coastal stations of the Bay of Bengal, for comparing between seasons, between day and night, between stations in different latitudes.

Source	dof	MSS	F ratio
Seasons(A)	3	1.7452	6.7674**
Day/Night(B)	1	0.0539	0.2090^{ns}
Latitudes(C)	4	0.7071	2.7417^{b}
AB interaction	3	0.2573	0.9975^{ns}
BC interaction	4	0.2132	0.8268^{ns}
AC interaction	12	0.7567	2.9342*
Error	12	0.2579	
Total	39		

Table 4.6b 3 Way ANOVA for mesozooplankton biomass in the mixed layer and Thermocline layer of the oceanic stations of the Bay of Bengal, for comparing between seasons, between day and night, between stations in different latitudes.

Source	dof	Oceanic stations				
		F ratio				
		MLD	**Thermo cline**	**300-BT**	**500-300**	**1000-500**
Seasons(A)	3	3.0070^{a}	3.7866*	2.0803^{d}	4.9210*	0.5135^{ns}
Day/Night(B)	1	2.9015^{c}	0.1513^{ns}	0.1257^{ns}	0.0084^{ns}	0.3476^{ns}
Latitudes(C)	4	2.7372^{b}	1.0563^{ns}	0.3829^{ns}	2.6916^{b}	1.3096^{ns}
AB interaction	3	1.0741^{ns}	0.7091^{ns}	1.6511^{h}	0.6157^{ns}	1.0055^{ns}
BC interaction	4	0.7379^{ns}	0.2274^{ns}	0.7217^{ns}	1.7118^{g}	0.7851^{ns}
AC interaction	12	1.7732^{e}	1.7391^{f}	0.7246^{ns}	2.3058^{b}	0.9277^{ns}
Error	12					
Total	39					

dof- degrees of freedom, F ratio- F statistic used for the test

Calculated F statistic is significant (*)at 5% level ($P < 0.05$), (**) at 1% level ($P < 0.01$), (^{a}) at 7%level ($P < 0.07$), (^{b}) at 8%level($P < 0.08$), (^{c}) at 11%level ($P < 0.11$), (^{d}) at 16%level ($P < 0.16$), (^{e}) at 17%level ($P < 0.17$), (^{f}) at 18%level ($P < 0.18$), (^{g}) at 21%level ($P < 0.21$), (^{h}) at 23%level ($P < 0.23$), (^{ns}) not significant

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Chapter - 5

DIEL VERTICAL MIGRATION OF MESOZOOPLANKTON IN THE ARABIAN SEA AND THE BAY OF BENGAL

5.1 Introduction

Zooplankton regularly undertake daily vertical movements through the water column, a behaviour generally termed as diel vertical migration (DVM) (Enright, 1977; Angel, 1989; Uye *et al.*, 1990). The normal pattern of DVM for zooplankton is to occupy greater depths during the day and shallower depths at night.The amplitude of DVM may be several hundreds of meters in oceanic zooplankton, with deep daytime fasting and shallower nighttime feeding (Longhurst, 1985). The rate of DVM vary between species and from a few metres to several hundred metres.

Net transport of organic material is facilitated through vertical migration of zooplankton (e.g., Longhurst and Harrison, 1988) and physical mixing of dissolved organic matter (Copin- Montehgut and Avril, 1993). Zooplankton can facilitate the vertical flux of organic material in two ways (Angel, 1984). The packaging of material into rapidly sinking fecal pellets is considered 'passive' transport since organisms do not participate directly in the vertical movement. Alternatively, 'active' transport occurs when vertically migrating organisms accelerate the transfer of organic material to depth as gut contents to be either defecated, or assimilated into biomass, and then respired or consumed by predators at depth (Longhurst and Harrison, 1988; Longhurst et al., 1990).

Diel and ontogenic migration of zooplankton is proposed to be one of the important mechanisms in transporting carbon from the euphotic zone to the deep water (Longhurst and Harrison, 1988; Longhurst et *al.,* 1990; Dam *et al.,* 1995a). Diel migrant mesozooplankton are usually below the euphotic zone by day and within the euphotic zone by night. A portion of the organic carbon grazed by diel migrant mesozooplankton through nocturnal feeding (in the euphotic zone), is released as respiratory carbon, during the daytime below the euphotic zone by returning migrant mesozooplankton. Longhurst *et al.* (1990) and Dam *et al.* (1995a) showed that the amount of respiratory carbon transported from the euphotic zone by diel migrant mesozooplankton can be, at times, of the same order of magnitude as that of the gravitational particle sinking. When deep mixing does not occur, diel migration by zooplankton could provide a supply of DOC to the deeper layers for the microbial community. Longhurst and Harrison (1988) suggested that migrating zooplankton play an important role in vertical flux through a more subtle process, by consuming organic particles at the surface at night and respiring the inorganic nutrients below the mixed layer during the day. Vertically migrating zooplankton can actively transport a significant amount of dissolved inorganic carbon (CO_2, as estimated by O_2 consumption) and nitrogen (NH_4) to deep water (Longhurst and Harrison, 1988; Longhurst et al., 1989,1990; Dam et al., 1995; Zhang and Dam, 1997; Le Borgne and Rodier, 1997; Hays et al., 1997) for total N flux.

Many possible mechanisms underlying DVM have been proposed, among which, the visual predator-avoidance hypothesis is most supported and accepted (Hardy and Gunther, 1935; Zaret and Suffern, 1976; Bollens and Frost, 1992; Pearre, 2003). i.e zooplankton descend to dim lit areas during the day to avoid visual predators and ascend to feed during night. This reduces the risk of mortality from predators such as fish. Besides, food may be the second important factor affecting the vertical distribution of zooplankton. Hardy and Gunther (1935) suggested that migrating behaviour may be modified by hunger and, thus the hunger–satiation hypothesis emerged. Light can mediate strong effects on the avoidance behavior (Ringelberg, 1995), in addition to environmental parameters such as temperature (McLaren, 1963), dissolved oxygen (Weider and Lampert, 1985) and can modify the profile of DVM. DVM performers are also found to increase migration range with ontogenetic development (McLaren, 1963; Zaret and Suffern, 1976; Uye *et al.*, 1990). DVM is thought to maximize energy gain and reduce daylight predation (De Robertis et al. 2000; Rollwagen Bollens and Landry 2000; Strom 2002; Tarling et al. 2002) and, in turn, affecting the carbon flux from the euphotic zone (Richardson et al. 2004; Roman et al. 1995).

This chapter deals with the diel vertical migration of mesozooplankton during different seasons observed in the Arabian Sea and the Bay of Bengal; an attempt is also made to determine which groups perform diel migration and contribute to vertical carbon flux. As mentioned in chapter 2, one coastal and one oceanic station from each transect were sampled four times a day at 6hr interval. Thus representing two night and two day samples. The average biomass obtained for day and night are presented here.

5.2 Environmental characteristics

The hydrographic and the biological features during various seasons of both Arabian Sea and the Bay of Bengal are explained in chapter 3 and 4 respectively.

5.3 Vertical migration of mesozooplankton in the coastal and oceanic regions of Arabian Sea

Mesozooplankton biomass variations in the coastal region clearly showed that the diel vertical migration was more pronounced during fall intermonsoon and summer monsoon of the AS. The night biomass in the mixed layer was higher than the day biomass during fall intermonsoon (Fig. 5.1c). No significant difference between the day and night biomass was detected during spring inter monsoon. The average migratory biomass in the MLD (Table 5.1) during the fall inter monsoon was 0.28 ml.m^{-3} The rate of migration of mesozooplankton varied between the southern and northern coastal regions (Fig 5.5). During fall inter monsoon, the migratory biomass was the highest in the southern latitudes (10°N, 13°N, and 15°N, Fig. 5.1a & 5.5). Major taxa contributing to their abundance to the high migratory biomass during this season were ostracods (81.03 ind.m^{-3}), euphausiids (8.03 ind.m^{-3}), copelates and salps (6.09 ind.m^{-3}). Euphausiids (52.8ind.m^{-3}) and siphonophores (56.3ind.m^{-3}) were exhibited significant DVM behavior during summer monsoon mostly at 8°N latitude. It has been clear that the mesozooplankton in the coastal regions of the Southern AS exhibited high night time biomass in all summer and fall intermonsoons (Fig.5.1a).

DVM was prominent in the oceanic regions during most of the seasons. It was more pronounced during summer monsoon followed by spring inter monsoon and winter monsoon (Fig 5.2). During summer monsoon, DVM was prominently at all the latitudes but during the spring inter monsoon it was occurred at 13°, 17°, and 21 °N latitudes (Fig.5.5).

The average migratory biomass during the summer monsoon and spring inter monsoon were 1.15 ml.m^{-3} and 0.1 ml.m^{-3} The major migrant taxa during summer monsoon were (Table 5.1) copepods, euphausiids and siphonophores whereas during spring they were ostracods, appendicularians and decapods (Table 5.3). The rate of DVM was less during winter monsoon compared to other seasons.

5.4 Vertical migration of mesozooplankton in the coastal and oceanic regions of the Bay of Bengal

The maximum DVM along the coastal stations was observed during summer monsoon followed by spring intermonsoon and winter monsoon. The average migrant biomass in the MLD during the summer monsoon was 0.43 ml.m^{-3} At all latitudes, (11 to 19 °N), the night biomass (Fig. 5.4) was higher during summer monsoon. The highly migrant taxa during summer monsoon were ostracods (105 ind.m^{-3}), Siphonophores (9.54 ind.m^{-3}), medusae and polychaetes. Copepods were much more abundant in the MLD of the coastal stations (Table 5.4) than the deeper strata during winter monsoon (147 ind.m^{-3}) and spring inter monsoon (48 ind.m^{-3}).

In the oceanic regions of the BoB the highest DVM was observed during summer monsoon and spring Intermonsoon (Fig. 5.4). However, seasonal peaks in the biomass of zooplankton varied depending on the sampling location. During spring intermonsoon there was no substantial migration of mesozooplankton was observed in the MLD. Higher night biomass during summer was recorded at 13, 15, and 19°N transects, whereas during spring and winter it was at northern latitudes (Fig.5.5). During summer, ostracods (104 ind.m^{-3}) accounted for the highly migrant taxa whereas copepods (74 ind.m^{-3}) was the highly migrant taxa during spring inter monsoon (Table 5.6).

5.5 Statistical Analysis

3 way ANOVA applied to compare between seasons, between day and night and between stations based on mesozooplankton biomass in the AS coastal, oceanic and BoB coastal and oceanic stations. Day and night variations observed in the biomass of the mixed layer of AS coastal stations were not significant (Table* 3.6a). D/N variation observed in biomass in the thermocline layer was only due to sampling fluctuations ($P > 0.05$). In oceanic stations, the mixed layer of AS showed seasonal variation ($F_{(3,\ 19)} = 3.4383$, $P < 0.05$) as well as D/N variations in mesozooplankton biomass and were highly significant ($F_{(1,\ 18)} = 3.8583$, $P < 0.07$). But all the first order interactions were due to sampling variability indicating that the variations observed in biomass in different seasons were independent of day and night difference ($P > 0.05$) (Table* 3.6a & 3.6b). In the thermocline layer of the open ocean stations, biomass variation in D/N were related to seasons as indicated highly season – D/N interaction ($F_{(3,\ 18)} = 2.3486$, $P < 0.11$) but at a lower level of confidence, at 8% only. In 300-BT stratum, variations observed in mesozooplankton biomass in the open ocean, with respect to D/N ($P > 0.05$) were due to sampling variability and the differences were not significant. In 300-500 stratum in the open ocean, day and night differences were significant at 8% level ($F_{(1,\ 18)} = 3.4462$, $P < 0.08$) with insignificant latitudinal variations ($P > 0.05$). This means that the seasonal and diurnal variations observed remained similar in all the studied stations ($P > 0.05$). In 1000-500 stratum in the open ocean only seasonal variations were high ($F_{(3,\ 18)} = 3.065$, $P < 0.07$) and these seasonal day and night variations remained same in all the stations ($P > 0.05$) (Table* 3.6a & 3.6b).

Day and night variations observed in mesobiomass in the mixed layer of BoB coastal stations were not significant (Table 4.6a).

In the open ocean stations, mesozooplankton in the mixed layer varied significantly with respect to diurnal variation (F(1, 12) = 2.9015, P < 0.11) and with respect to latitudinal variations, $F_{(4,\ 12)} = 2.7372$, P < 0.08) with high dependency for stations on seasons ($F_{(12,\ 12)} = 1.7732$, P < 0.17). In 300-BT layer in the open ocean seasonal influence on day and night variation was at a lower level of confidence $F_{(3,\ 12)} = 1.6511$, P < 0.23), (7.7%). In 300-500 depth stratum in open ocean, day and night – station interaction (F(4,12) = 1.7118, P <0.21) were high, indicated that day and night variation were significant in some stations (Table 4.6b In the 1000-500 depth layer variations observed in the different seasons during D/N at same stations are due to sampling fluctuations, but are not features of mesozooplankton biomass at this depth (P>0.05) (Table* 4.6a & b).[*]

5.6 Discussion

Seasonal variations in the DVM of mesozooplankton in the AS and BoB were compared in the present study. The coincidence of biological and physical data permitted a closer and detailed examination of the factors influencing the DVM of zooplankton. Most of the studies on DVM has been conducted, since most studies has been conducted at north western Indian Ocean and only a few studies have been made from the Arabian Sea. The earliest records of DVM from the North West Indian Ocean are by Vinogradov and Voronina, (1961) and Timonin, (1995). Mathew *et al.*, (1990a, b, and c) and Paulinose *et al;* (1992) reported DVM in the south eastern Arabian Sea.This is the first study to describe the diel vertical migration of mesozooplankton and its seasonal variation.

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[*] Note: Table*3.6a&3.6b is in the chapter 3
Table*4.6a&4.6b is in the chapter 4

Seasonal change in DVM was apparent from the estimates of day and night zooplankton biomass, both in the AS and BoB. Rates of migration of zooplankton differed between coastal stations and the oceanic stations of AS and appeared to be related to the hydrographical conditions of the respective seasons, such as stratification, primary production, water temperature and DO.

During spring intermonsoon (SIM, March– May), no clear and consistent diel vertical migration patterns were noticed in the coastal and oceanic stations of the AS and BoB. However, compared to coastal stations, mesozooplankton in the oceanic stations exhibited elevated migratory behaviour in AS. During SIM, the entire AS attains a typical tropical structure (oligotrophy). Prasannakumar &Prasad (1996) reported that during this season, the South Eastern Arabian Sea is undergoes primary heating, characterized by weak winds and intense solar radiation, making the surface layer highly stratified. In the BoB, Spring Inter monsoon is indicative of the warming of surface waters, which results strong and a stratified water column (Varkey *et al.*, 1996). The concentration of chl *a* and primary productivity was very low compared to other seasons. The stratification may limit the vertical migration of some species (Fragopoulu &Lykakis, 1990). In addition, in search of food, animals will always stay in the surface waters to avoid starvation even without considering the predation pressure, and thereby maximize the venturous revenue (Huntley and Brooks, 1982). The high nutrient concentrations below the mixed layer resulted in the development of a subsurface chlorophyll maximum (SCM) during SIM. This could provide food at the deeper waters and hence the zooplankton stay in deeper waters for longer periods (day and night). Extensive blooms of blue-green algae *(Trichodesmium)* were observed in the northern AS during this study. During SIM, day time biomass was almost similar to the night biomass possibly due to the low abundance of predators. Steele and Henderson (1998) reported that during spring, the increase in the density of bloom not only increases the turbidity and affect the visibility of predators to mesozooplankton, but also reduces the efficiency of tactile predators. This is consistent with the present observations during this season, where the migrators were copepods, copelates, salps and ostracods etc. Angel (1979) has discussed the migratory behaviour and predator avoidance in halocyprid ostracods. Copepod abundance in the surface may be due to their aggregation for spawning. It has been reported that spring is the period when the diapausing copepods from the previous year rise to the surface to make their final molt and spawn. They will be large (Fiksen and Carlotti, 1998)in size, and feeding and growing at maximum potential (Uye *et al.*, 1990), thus remaining within a zone of unlimited food offers the best survival strategy.

During SM, the DVM of mesozooplankton was prominent in the southern regions of both AS and BoB. Mesozooplankton in the northern open ocean regions also exhibited comparatively high DVM.The enrichment of the mixed layer by coastal upwelling could be the reason for subsequent high production in the southern coastal regions.. In the northern AS, nutrients were supplied by open ocean upwelling induced by positive wind stress curl. In southern coastal areas, upwelling of subsurface waters brings nutrients to the euphotic zone and eventually, results in the high biological production (Banse, 1968). During this period nutrient seems to be advected to southern open waters from the upwelling areas of the western AS (Prasanna kumar *et al.*, 2001). Thus, AS remains highly productive during SM with increased phytoplankton levels in the surface. LaFond (1957), Murty and Varadachari (1968), Shetye et al. (1991) and Rao (2002) have reported upwelling along the coasts of the BoB during summer monsoon. The wind driven vertical advection and mixing causes the replenishment of the nutrient concentrations in the upper layers of the BoB during summer monsoon (Bhavanarayana *et al.,* 1957; Udayavarma *et al.*, 1959) and resulting in high biological production. During SM, the DVM was prominent in the Southern Bay. It may be explained through the high production as a result of coastal upwelling, whereas large quantities of fresh water from rivers freshens northern BoB, which leads to the formation of barrier layer, stratification and highly stable upper layers (Pankajakshan *et al.*, 2007a). DVM can increase due to upwelling, enhanced primary productivity and depth of habitat (Genin,2004). There are strong indications that diel vertical migrations in upwelling areas are directly linked to food availability Each pulse of upwelling deep water provides the necessary nutrients for a growth spurt of phytoplankton. This can be observed as the migration occurs only when increased food at the surface encourages upward migration (Gliwicz & pijanowska, 1988). DVM of zooplankton has been attributed to an evolved strategy of foraging in the phytoplankton-rich photic zone during darkness and avoiding mortality due to predators by residing deeper in the water column during daylight (Gliwicz, 1986). Examination of the migrator biomass of different size-fractions revealed that DVM was performed occurred most strongly by larger animals. The major migrant taxa during summer monsoon were euphausids, chaetognaths and siphonophores. Rodriguez and Mullin (1986) has explained the greater susceptibility of larger animals to visual predators and hence, their urge to descend and spend the daytime at darker depths. Increased diel vertical migrations have also been attributed to fast swimming of large zooplankton in comparison to smaller congeners, and to increased light and the depth of the mixed layer (Longhurst 1976). Mauchline and Fisher (1969) reported that euphausiids are one of the strongest diel vertical migrators. Chaetognaths are voracious nocturnal feeders (Gibbons & Stuart 1994), and it is possible that they keep the numbers of copepods low or that some species of copepods show reverse migration to escape predation. Zooplankton diel vertical migration is commonly observed in oceanic areas, and our results also show that DVM was a strong feature in the oceanic areas of both southern and northern AS, especially during summer monsoon.

The same can apply to the fall Intermonsoon (FIM). DVM observed during FIM followed similar pattern with lesser intensity than that of SM. Coastal upwelling is very active during summer monsoon in the south eastern Arabian Sea even after the withdrawal of monsoon (ie, fall inter monsoon). When the upwelling recedes, the water column is regaining to the stable condition and sustains optimum nutrients, which in turn, supports high biological production. In October, when the summer monsoon has already ceased, enhanced biological production appear in the upwelling zones in the Arabian Sea (Banzon *et. al.,* 2004). High migratory behaviour can be attributed to this when increased food levels at the surface make upward migration (Gliwicz & pijanowska, 1988).The results were consistent with the observations made by Huntley and Brooks, (1982) that, the amplitude of DVM gradually declines towards the end of summer. Fall Inter monsoon and southwest monsoon have documented the substantial diel migrations of fishes and zooplankton (Luo *et al.*, 2000). The important migrators in the oceanic regions during this season were copepods, ostracods, siphonophores, chaetognatha, euphausiid, salps and copelata. Recently, there has been evidence to support for predator avoidance causing diel vertical migration in crustacean holoplankton. Calanoid copepods are generally known to display this kind of migrating behaviour and a nocturnal increase in feeding (Daro, 1988; Dagg and Grill, 1980). During all the seasons, salps showed a significant migration except during winter monsoon. There are reports (Wiebe *et al.*, 1979), reports that the massive groups of colonial gelatinous organisms such as salps showed Iongest shifts between day and night and may contribute markedly to the food requirement of bathypelagic and benthic animals.

During winter monsoon, the day night difference of zooplankton biomass was very low and there is no significant DVM in AS and BoB. Intrusion of low saline, warm, BoB waters into the SEAS makes stratified upper layers (Prasanna kumar *et al,* 2003), which in turn, reduces the production. The north easterly winds prevailed over the northern BoB during winter, cools the surface layers resulting an inversion layer beneath, which enhances the stability of subsurface layer and prevent vertical mixing (Balachandran *et al.*, 2008). In addition, high river runoff brings sediments and this turbid water column prevents solar penetration and reduces production. The oceanic regions of the southern BoB also exhibited thermohaline stratification during this season. Low surface production and high stratification act as an absolute barrier to limit the DVM in the AS and BoB. Huntley and Brooks, (1982) reported that when food is scarce in the surface waters, the usual DVM performers stop vertical migration until food concentrations are enough to support it. Hirakawa *et al, (*1990) suggested that predation and thermal stratification might be two important factors influencing the DVM of zooplankton in southern Japan Sea. Northern AS displayed to some extent of DVM than southern AS. It can be substantiated by the high primary production through winter cooling. The cool and dry continental air enhance the evaporation, which leads to the surface cooling and initiates the convective overturning in the northern AS. Densification of surface waters in turn, leads to deep MLDs injecting nitrate into the surface layers and accelerate biological production (Madhupratap *et al.*, 1996; Jyothibabu *et al.*, 2003; Balachandran *et al.*, 2008). The migrators in the oceanic stations of NEAS were copepods, ostracods, salps, doliolids, fish larva, chaetognaths etc. Many of the biotic and abiotic factors such as food abundance and distribution, predation pressure and hydrographical heterogeneities, may interactively influence the DVM of copepods (Hirakawa *et al.*, 1990).

Fish larvae was showed significant migration behaviour in almost all the seasons in both AS and BoB except winter monsoon in the coastal AS (Table 5.2, 5.3, 5.5&5.6). Nocturnal migration into warmer water at night after feeding on benthic prey species was observed in larval fish species.The upward migration promoted digestion, thereby allowing greater feeding and growth to result in three times faster growth than if they had remained in the cold deeper depths.

DVM of mesozooplankton in the AS and BoB showed that it was more prominent during the highly productive season like summer monsoon. The study showed that compared to the DVM between AS and BoB, the highest DVM of mesozooplankton was seen in the AS. The study showed that there were clear associations between DVM and environmental characteristics such as chlorophyll *a* concentrations and stratification. Both periods of extended migration (summer monsoon& fall inter monsoon in AS and summer monsoon in BoB) occurred when elevated concentrations of chlorophyll *a* were observed. These observations suggest that diel vertical migration may be advantageous only when sufficient food is available in the upper water column (Pearre, 1979). The DVM was not associated with periods of stratification; our most extended periods of DVM were observed when stratification was absent. These results were also similar with the studies made by Ashjian *et al* (1998) in the Mid-Atlantic Blight. Efforts to quantify the vertical elemental flux caused by DVM of mesozooplankton have been restricted some regions only (Longhurst and Harrison, 1988) and, consequently, the extent of DVM on more spatially extended scales will be the important step in the future.

Statistically significant difference was observed in the zooplankton samples of night and day from different seasons from the oceanic regions of both AS and BoB than coastal regions. Goswami *et al* (1992) in the eastern AS, BoB estimated that the ratio between the day and night biomass was higher than one, but it was never double. Achuthan kutty *et al* (1992) estimated a lower day time biomass in the upper layers than the lower layers in the eastern AS, for the summer monsoon. In conclusion, our observations suggest that diel vertical migration was an important feature of the zooplankton community in the southern AS and BoB during summer monsoon and those vertical migrant zooplankters may have caused a significant removal of carbon from the surface layers. From our analysis, it is clear that the occurrence of the DVM in both AS and BoB was a function of multiple factors, both physical and biological, that interacted to produce the observed patterns.

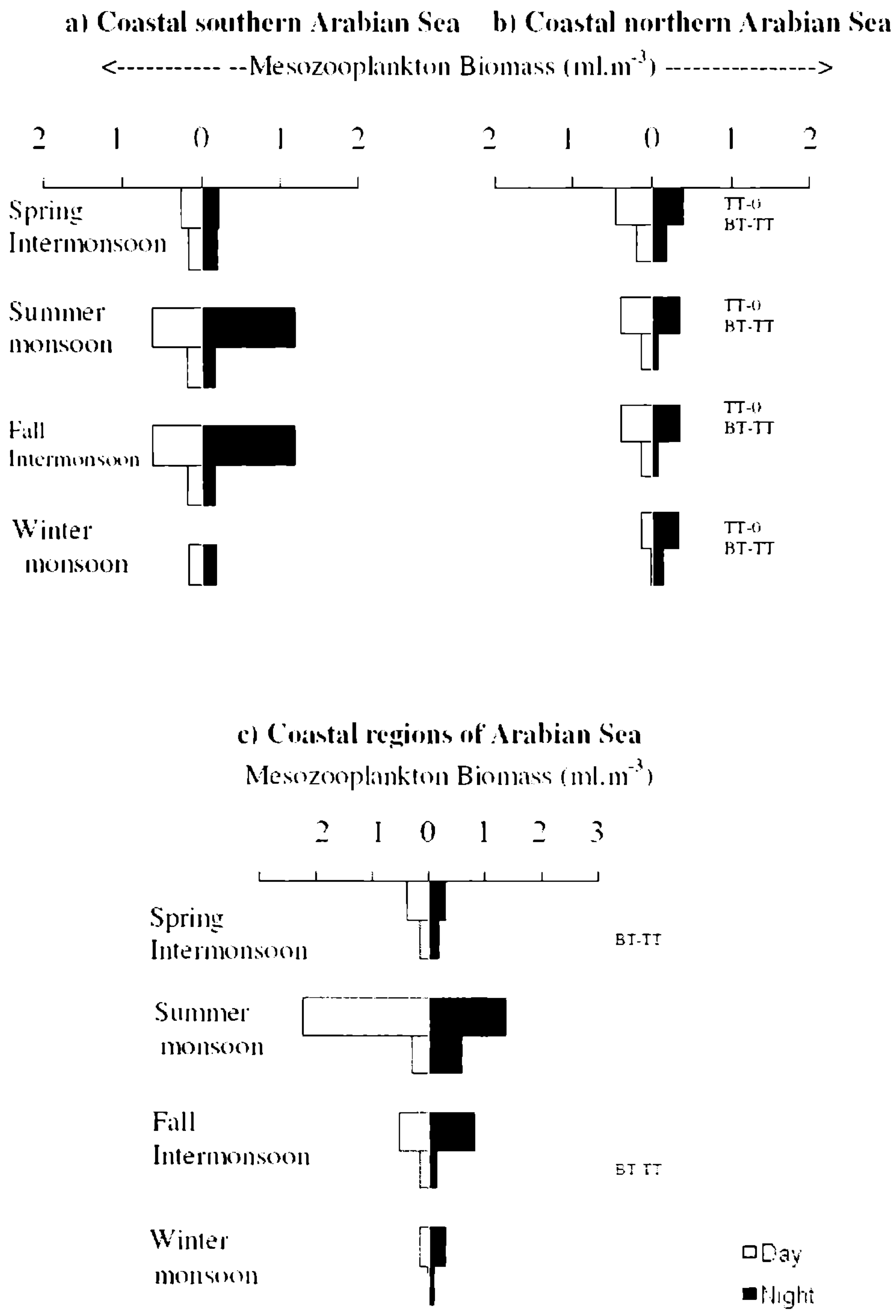
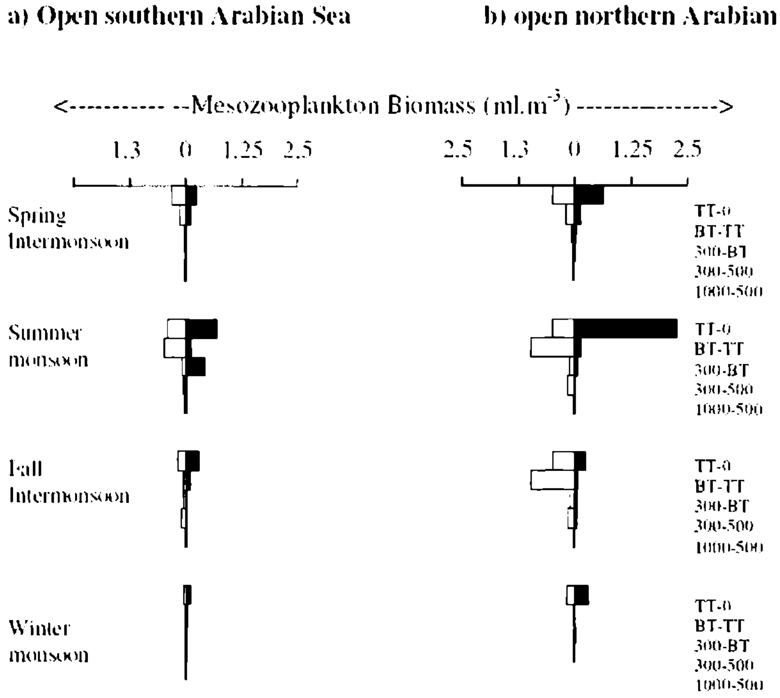


Fig. 5.1. Diel vertical migration of mesozooplankton in the coastal regions of Arabian Sea during different seasons


a) Open southern Arabian Sea

b) open northern Arabian Sea

c) Open ocean regions of Arabian Sea

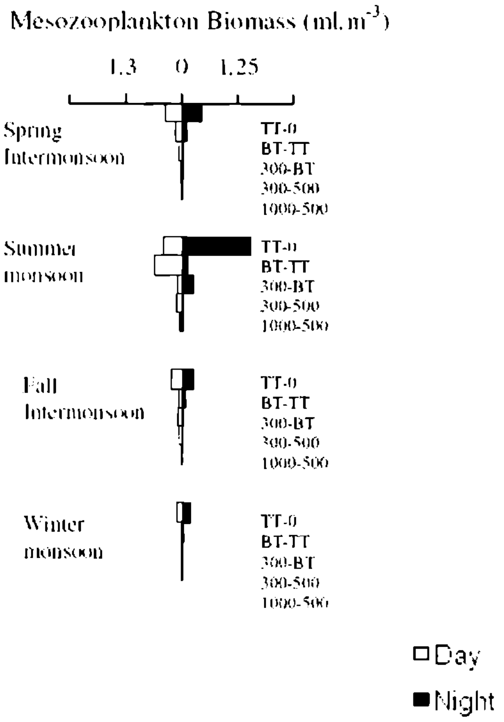


Fig. 5.2. Diel vertical migration of mesozooplankton in the oceanic regions of Arabian Sea during different seasons

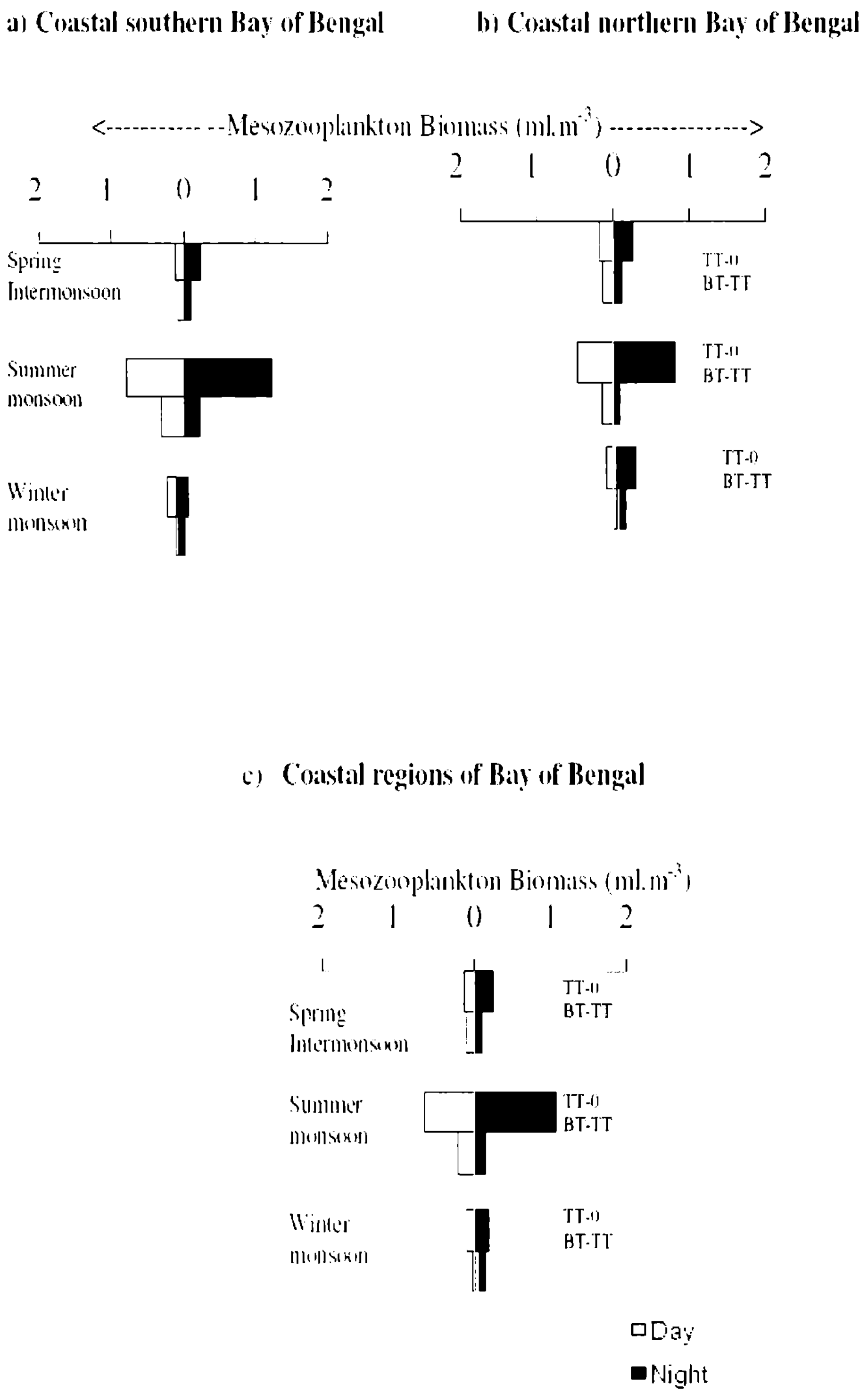
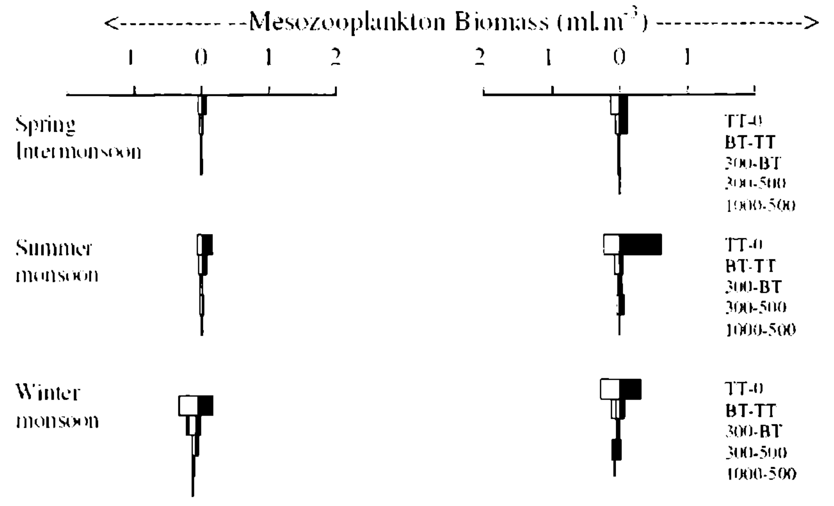


Fig. 5.3. Diel vertical migration of mesozooplankton in the coastal regions of the Bay of Bengal during different seasons

a) Open southern Bay of Bengal b) Open northern Bay of Bengal



c) Open ocean regions of Bay of Bengal

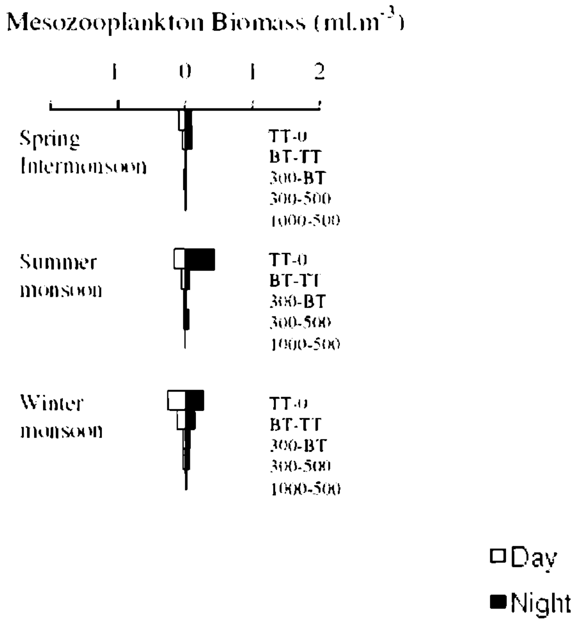


Fig. 5.4. Diel vertical migration of mesozooplankton in the oceanic regions of the Bay of Bengal during different seasons

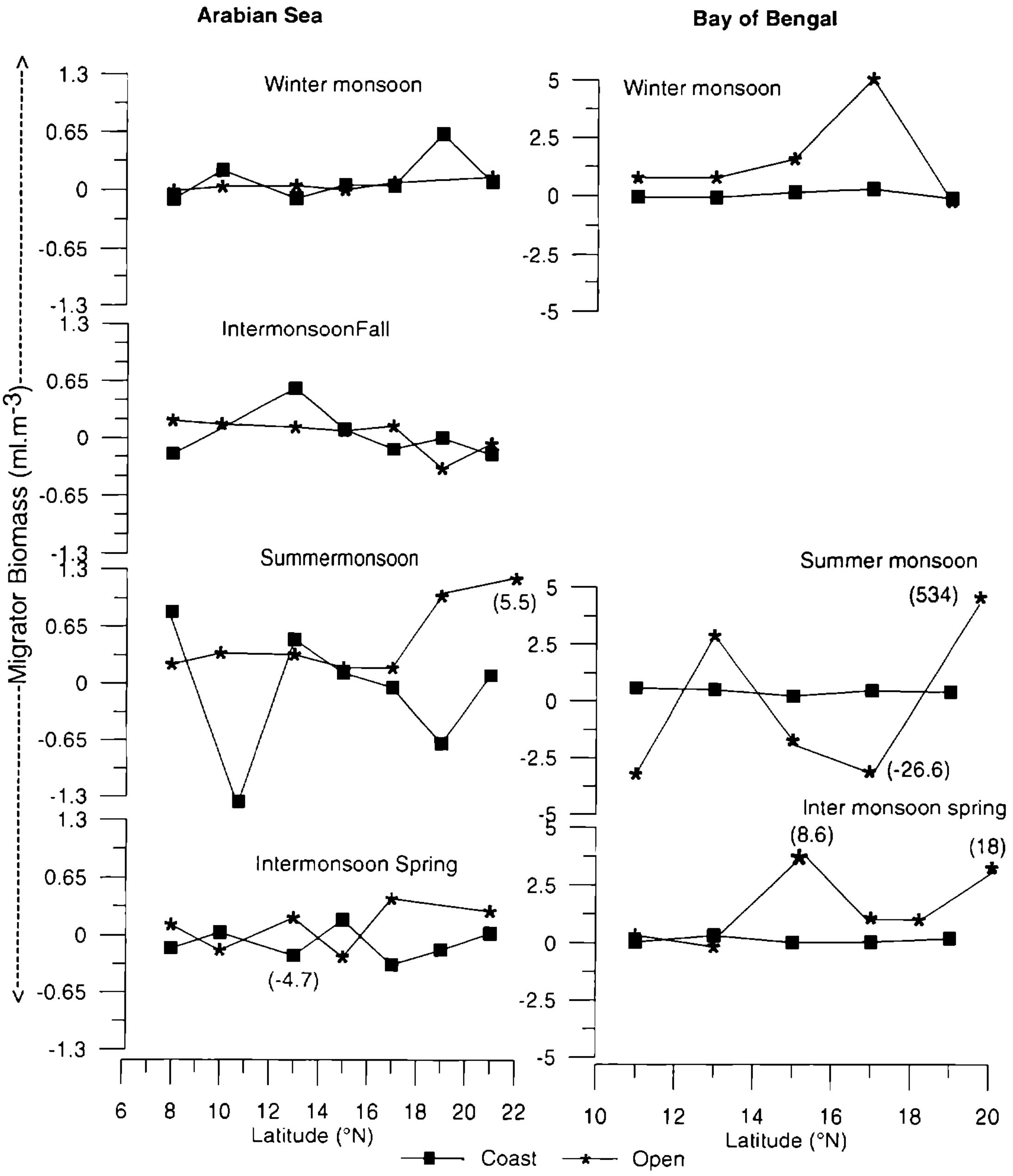


Fig. 5.5. Migrator biomass of mesozooplankton in the Coastal and Open ocean regions of the mixed layer of the Arabian Sea and Bay of Bengal

Table.5.1 Mesozooplankton migratory biomass (ml.m^{-3}) in the coastal and oceanic regions of Arabian Sea during different seasons

Seasons		SIM		Migrator biomass	SM		Migrator biomass	FIM		Migrator biomass	WM		Migrator biomass
Day/Night	**DEPTH**	**Day**	**Night**		**Day**	**Night**		**Day**	**Night**		**Day**	**Night**	
Coastal	**MLD**	0.39	0.30	-0.09	2.25	1.37	-0.88	0.53	0.81	0.28	0.20	0.23	0.03
	Thermocline	0.17	0.18	0.02	0.30	0.48	0.18	0.16	0.13	-0.02	0.04	0.09	0.05
Open	**MLD**	0.35	0.45	0.10	0.41	1.56	1.15	0.24	0.28	0.04	0.11	0.17	0.06
	Thermocline	0.13	0.12	-0.01	0.60	0.14	-0.46	0.05	0.08	0.02	0.02	0.03	0.01

Table 5.2 Rate of migration of various mesozooplankton taxa (ind.m^{-3}) in the mixed layer of the coastal regions of the Arabian Sea during different seasons.

Seasons	SIM			SM			FIM			WM		
Zooplankton Taxa (ind.m^{-3})	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**
Medusa	0.18	0.48	0.30	6.18	3.03	-3.15	0.18	1.59	1.41	0.10	0.10	0.00
Siphonophore	0.42	0.37	-0.05	3.16	56.31	53.15	0.91	1.72	0.81	0.31	0.12	-0.19
Polychaeta	1.15	1.63	0.48	0.78	2.10	1.32	3.59	2.25	-1.34	1.57	1.59	0.02
Ostracoda	7.78	24.74	16.96	143	43.26	-100	20.27	101.30	81.03	30.23	7.83	-22.40
Copepoda	334.04	332.66	-1.38	1294	739	-555	1215	948	-267	237	94.54	-142
Amphipoda	0.60	1.32	0.72	3.47	3.86	0.39	1.52	3.15	1.63	1.43	1.80	0.37
Euphausiid	2.65	4.86	2.21	5.55	58.35	52.80	0.85	8.88	8.03	1.58	1.43	-0.15
Decapoda	1.60	3.20	1.60	19.29	8.93	-10.36	9.45	10.77	1.32	2.72	3.57	0.85
Chaetognatha	24.21	29.87	5.66	37.57	39.89	2.32	37.17	32.05	-5.12	37.01	13.64	-23.37
Copelata	14.73	30.45	15.72	5.14	6.63	1.49	48.15	54.73	6.59	9.05	3.40	-5.65
Salpa	1.14	5.97	4.83	0.00	0.02	0.02	3.30	9.38	6.09	2.32	0.44	-1.87
Doliolida	0.20	0.50	0.30	0.62	0.96	0.34	2.66	0.97	-1.69	0.26	0.13	-0.14
Fish larva	0.58	0.65	0.07	2.01	1.43	-0.57	0.93	0.76	-0.17	1.24	0.94	-0.30

Table 5.3 Migration of various mesozooplankton taxa (ind.m^{-3}) in the mixed layer of the oceanic regions of the Arabian Sea during different seasons

Seasons	SIM			SM			FIM			WM		
Zooplankton Taxa (ind.m-3)	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**
Medusa	0.17	0.32	0.15	0.24	0.21	-0.03	0.07	0.19	0.12	0.12	0.18	0.06
Siphonophore	0.23	0.28	0.05	0 19	1.41	1.22	0.09	0.13	0.03	0.10	0.13	0.03
Polychaeta	1.65	1.06	-0.58	1.51	0.85	-0.65	1.33	3.23	1.89	0.62	1.52	0.90
Ostracoda	9.85	75.74	65.90	75.67	68.36	-7.31	14.44	172.24	157.80	3.60	38.33	34.73
Copepoda	287.13	278.77	-8.36	154.23	161.68	7.45	299.32	519.31	219.99	79.20	146.73	67.53
Amphipoda	0.72	0.32	-0.41	1.69	0.55	-1.14	0.52	1.14	0.62	0.14	0.43	0.29
Euphausiid	0.58	0.69	0.10	3.20	4.56	1.36	0.13	3.34	3.21	0.62	2.18	1.55
Decapoda	1.90	2.54	0.63	8.39	5.35	-3.05	2.04	2.46	0.42	2.95	5.01	2.07
Chaetognatha	19.47	15.33	-4.14	22.41	16.39	-6.02	14.15	15.93	1.79	12.07	15.65	3.58
Copelata	10.39	14.56	4.17	0.53	0.60	0.07	8.11	10.57	2.47	6.63	6.88	0.25
Salpa	1.26	0.23	-1.03	1.96	2.82	0.86	0.38	0.03	-0.35	0.03	0.07	0.05
Doliolida	0.26	0.25	-0.01	0.23	0.53	0.30	1.24	0.67	-0.58	0.48	0.91	0.43
Fish larva	0.22	0.41	0.19	0.17	0.48	0.31	0.18	0.73	0.55	0.28	1.07	0.79

Table 5.4 Mesozooplankton migratory biomass (ml.m-^{3}) in the coastal and oceanic regions of the Bay of Bengal during different seasons.

Seasons		SPIM		Migrator biomass	SM		Migrator biomass	WM		Migrator biomass	
Day/Night	**DEPTH**	**Day**	**Night**		**Day**	**Night**		**Day**	**Day**	**Night**	
Coastal	**MLD**	0.13	0.25	0.12	0.66	1.09	0.43	1.08	0.09	0.19	0.1
	Thermocline	0.10	0.10	0.00	.21	0.15	-0.06	0.23	0.04	0.09	0.05
Open	**MLD**	0.10	0.10	0.00	0.18	0.44	0.26	0.28	0.29	0.27	-0.02
	Thermocline	0.04	0.09	0.05	0.06	0.06	0.00	0.13	0.08	0.05	-0.03

Table 5.5 Migration of various mesozooplankton taxa (ind.m^{-3}) in the mixed layer of the coastal Regions of the Bay of Bengal during different seasons

Seasons	**IntermonsoonSpring**			**SEM**			**NEM**		
Zooplankton Taxa (ind.m-3)	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**
Medusa	0.06	0.05	-0.01	2.30	3.88	1.58	0.44	0.06	-0.38
Siphonophore	0.56	1.98	1.42	7.73	17.27	9.54	3.58	3.50	-0.08
Polychaeta	0.71	0.45	-0.26	6.80	8.95	2.16	1.22	3.46	2.23
Ostracoda	0.92	6.61	5.69	42.90	148.24	105.34	7.02	6.75	-0.27
Copepoda	133.25	181.99	48.74	1096.73	789.15	-307.57	132.04	279.66	147.62
Amphipoda	0.36	1.66	1.30	1.50	2.42	0.91	1.44	2.26	0.82
Euphausiid	2.27	3.36	1.09	19.66	18.05	-1.61	4.80	7.61	2.81
Decapoda	2.58	4.27	1.69	19.63	17.64	-1.99	2.31	2.29	-0.02
Chaetognatha	15.83	27.26	11.43	35.12	31.74	-3.38	23.19	15.88	-7.31
Copelata	3.04	6.82	3.78	250.65	159.16	-91.49	9.92	12.79	2.87
Salpa	0.17	0.19	0.02	0.83	0.76	-0.08	0.00	0.33	0.33
Doliolida	0.13	0.03	-0.10	13.76	10.23	-3.53	0.58	0.00	-0.58
Fish larva	0.38	1.20	0.82	1.40	1.61	0.21	0.71	2.54	1.83

Table5.6 Migration of various mesozooplankton taxa (ind.m^{-3}) in the mixed layer of the oceanic regions of the Bay of Bengal during different seasons

Seasons	**IntermonsoonSpring**				**Summer monsoon**			**Wintermonsoon**	
Zooplankton Taxa (ind.m-3)	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**	**Day**	**Night**	**Migrator**
Medusa	0.09	0.18	0.09	0.00	0.40	0.40	0.73	0.20	-0.35
Siphonophore	0.96	1.84	0.88	9.46	8.42	-1.04	1.70	3.87	0.79
Polychaeta	0.38	0.87	0.49	1.94	3.18	1.24	1.60	1.36	-0.26
Ostracoda	1.06	6.64	5.58	15.41	119.86	104.44	4.25	3.19	2.21
Copepoda	65.16	139.61	74.45	443.53	471.84	28.31	815.10	279.77	-89.36
Amphipoda	0.09	1.55	1.46	0.95	2.47	1.51	1.08	1.66	0.12
Euphausiid	0.78	1.23	0.45	2.82	3.12	0.29	3.70	5.86	4.14
Decapoda	0.64	2.35	1.72	5.59	8.49	2.90	3.14	8.11	0.99
Chaetognatha	10.16	11.27	1.10	38.51	31.36	-7.14	25.47	24.36	0.55
Copelata	2.39	3.50	1.11	20.80	8.22	-12.57	13.58	18.15	9.33
Salpa	0.85	0.36	-0.49	0.88	0.34	-0.54	1.26	0.64	-1.10
Doliolida	0.08	0.18	0.09	0.14	0.29	0.15	0.87	0.37	0.37
Fish larva	0.03	0.13	0.10	0.49	1.23	0.74	0.19	0.52	-0.08

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Chapter - 6
OSTRACOD DIVERSITY IN THE ARABIAN SEA

6.1 Introduction

In this chapter, the seasonal distribution of planktonic ostracods in the Arabian Sea (inter monsoon spring, summer monsoon, fall inter monsoon and winter monsoon) is presented.

6.2 Hydrography

The seasonal hydrography and physico chemical characteristics of AS have been described in Chapter 3. Some species have affinity to Arabian Sea High Saline Water mass (ASHSW). For delineating the ASHSW from other water masses, the seasonal distribution pattern has been expressed in the form of T-S plots (Fig.6.6).

Temperature-Salinity relations in the A S showed warm low saline water in the upper layers during spring inter monsoon (Fig.6.6a). These waters are seen in the upper layer of southern Arabian Sea.

During summer monsoon, TS relations in the AS showed low saline and low temperature water overlapping with low temperature and high saline waters in the upper layers. Detailed analysis revealed that low temperature and high saline water were confined along the oceanic regions and low temperature and low saline waters were along the coastal regions. (Fig.6.6b).

During fall intermonsoon, TS relations in the AS did not show low saline and low temperature, but low temperature and high saline water was seen in the upper layers. Analysis revealed that the low temperature and high saline water existed (Fig.6.6c) in the south west coast of India during summer extended northward up to 17°N. Maximum salinity was observed along the 24 sigma-t level followed by another salinity maximum along 26.4 sigma-t and 27.2 sigma-t.

During winter monsoon, TS diagram of the AS showed warm low saline and low dense water in the upper layers. Analysis revealed that this water has the characteristics of the Bay of Bengal water and was seen only in the southern Arabian Sea. Maximum salinity core along the 24 sigma-t level can be seen in the subsurface layer in a wider area (Fig.6.6d).

6.3 Seasonal variation of planktonic ostracods

In all 51 species of ostracods, 50 belonging to the family Halocyprididae and one to Cypridinidae were found in the Arabian Sea. Of these 14 species were recorded for the first time within the ostracods community of this area (Table 6.2). The photographs of some of the species are shown in Plate 6.1a- l. The average abundance of ostracod during different seasons were, SIM 1279 ind.m^{-3}, SM -3988 ind.m^{-3}, FIM -2678 ind.m^{-3} and WM -1340 ind.m^{-3} The most abundant species in the Arabian Sea were *Cypridina dentata* and *Euconchoecia aculeata* and their abundances varied between seasons and depth strata. Mostly these species were confined to MLD and thermocline (Fig 6.1- 6.5). The bioluminescent species encountered in the AS were *Alacia alata, Cypridina dentata, Conchoecia subarcuata, Conchoecia magna, Conchoecila daphnoides, Conchoecissa imbricata, Orthoconchoecia bispinosa, Mikroconchoecia curta, Discoconchoecia elegans, Paraconchoecia spinifera.*

Spring Intermonsoon

The mean abundance of ostracods in the Arabian Sea during this season was 1279 ± 119 ind.m^{-3} irrespective of depth and coastal open variations (Fig 6.1a). About 43 species were identified during this season from the upper 1000 m water column (Table 6.1). The dominant species encountered during this season were *Cypridina dentata* (60% of the total abundance) and *Euconchoecia aculeata* (29%). *Conchoecia subarcuata* (5.91%), *Conchoecetta giesbrechtii* (0.67%), *Metaconchoecia rotundata* (0.62%) *Orthoconchoecia atlantica* (0.60%).

In the mixed layer the most abundant species was *C. dentata* with a mean abundance of 2328 ind.m^{-3} and *Euconchoecia aculeata* with 903 ind.m^{-3} In the thermocline layer, the abundance of *C.dentata* and *E.aculeata* decreased with an abundance of 921 ind.m^{-3} and 659 ind.m^{-3} And further deeper, their numbers (Table. 6.2) drastically declined (Fig.6.1a -6.5a). The highest abundant species in the 300 m -BT depth were *E.aculeata, M.rotundata, C.giesbrechtii and C.acuminata,* whereas in the 500-300 m depth strata, the dominant species was *D.elegans.* At 1000-500 m depth strata the ostracod abundance were very less and the major species encountered were *D.elegans* (3.1%), *C.magna* (8.68%), *C.giesbrechtii* (15.19%), *Paraconchoecia inermis* (8.22%) and *Proceroecia procera* (6.2%).

Summer monsoon

Compared to other seasons, the total abundance was high during this season (Fig 6.1b) with a mean abundance of 3966 ± 380 ind.m^{-3} About 48 species were recognized during this season (Table 6.1) and was dominated by *C. dentata* (64%) *E. aculeata* (24%) *C.subarcuata* (4.93%), *O. atlantica* (2.06%).

The mean abundance of ostracod in the MLD during this season was also higher (10660±1780 ind.m^{-3}) than the other seasons. In the MLD and thermocline layer, *C.dentata* and *E.aculeata* contributed about 67% & 64% and 23% & 31%, respectively to the total abundance. The maximum density of *E. aculeata* was seen during this season in both MLD and Thermocline. The other dominating species were *O.atlantica and C.subarcuata. O.atlantica* contributed 9% of the total abundance in the 300 m-BT layer (Table 6.2). The other important species encountered in the 300 m-BT ,500-300 m,1000-500 m were *C,giesbrechtii, M.curta, P.inermis, P.procera and P.spinifera* (Fig.6.1b -6.5b)..

Fall Intermonsoon

After summer monsoon the highest mean abundance of ostracods (2678 ind.m^{-3}) was recorded during this season (Table 6.1). In the MLD, maximum abundance of ostracods (>23142 ind.m^{-3}) was seen at latitudes 8°N, 72 °E; 10°N, 72°E and 13°N, 71°E (Fig 6.1c). In these latitudes *C.dentata* was the dominant species. In the MLD about 86% was contributed by *C.dentata,* whereas at thermocline it was about 92%. The remaining ostracod population was composed of *E.aculeata* (6%), *O.atlantica* (2.34%), *P.oblonga* (0.42%) and *P.inermis* (0.34%). At the 300 m-BT and 500-300 m layers (Fig.6.1c -6.5c), the most abundant species was *M. rotundata* with a contribution of 11.96% and 23.66%, respectively. *C. parvidentata* (11.16%), *M. rotundata* (9.63%), *M. curta* (9.77%) and *P procera* (13.54%) were the major species in the 1000-500 m depth (Table 6.2).

Winter monsoon

The total mean abundance of ostracods was 1340±135 ind.m^{-3} during this season. In the MLD the mean abundance was about 3394±635 ind.m^{-3} and 92% was contributed by *C.dentata* and 6% was by *E.aculeata*. The highest abundance of ostracods in the MLD was seen at 17 °N, 69 °E; 19 °N, 69 °E and 21 °N, 67 °E stations (Fig 6.1d). In the thermocline layer also the dominant species were *C.dentata* (1334 ind.m^{-3}) and *E.aculeata* (79 ind.m^{-3}). *M.rotundata* comprised 18.5% the major share of the 300 m-BT layer whereas *M.curta* (14.81%), *C.imbricata* (18.39%), *D.elegans* was found at 1000-500 m water column (Table 6.2).

6.4 Coastal and Oceanic variation of planktonic ostracods

The total abundance of ostracods in the MLD were observed during the summer monsoon (8911 ± 27039 ind.m^{-3}) followed by fall inter monsoon (6050 ± 14995 ind.m^{-3}) and winter monsoon (3385± 6315 ind.m^{-3}) in the coastal stations of the Arabian Sea. The MLD and the thermocline comprised mainly of *C.dentata* and *E.aculeata* (Table 6.2). However, *E.aculeata* and *C.dentata* were more abundant in the MLD during summer monsoon with an average of 1817 ind.m^{-3} and 6165 ind.m^{-3} In the thermocline layer, on the other hand, *C.dentata* was maximum during winter monsoon (4057 ind.m^{-3}) where as *E.aculeata* were abundant during spring intermonsoon. The temporal and spatial abundance of these species are presented in Fig.6.9&6.11. *O.atlantica* represented the third dominant species in the MLD and thermocline of coastal station during summer monsoon with an average of 364 ind.m^{-3} and 162 ind.m^{-3}, respectively. *C.giesbrechtii, C.magna, M.rotundata* were the other species occurred in the MLD during winter monsoon with mean numerical abundance was 18, 9 and 9 ind.m$^{-3,}$ respectively. *C.giesbrechtii* and *M.rotundata* were, however, encountered more in the thermocline with an abundance of 33 ind.m^{-3} and 64 ind.m^{-3}, respectively. Of all species recorded, only *M. curta, M.rotundata, O. atlantica, P. procera, P. spinifera* were collected during all the seasons from the coastal stations (Table 6.3) but, their abundance varied between seasons. *P.mamillata, P.dorsotuberculata, P.dasyophthalma, C. plinthina, M. caudata* were not present in the coastal stations.

In the oceanic stations the higher abundance of ostracods was encountered during winter monsoon (10746 ind.m^{-3}) and summer monsoon (10581 ind.m^{-3}). *C.dentata* was the most abundant species in MLD at most of the oceanic stations along the northern latitudes and had the lowest densities during spring with a mean abundance of 3444 ind.m^{-3} Marked seasonality was shown by this species, which was more abundant during winter monsoon with a mean abundance of 10671 ind.m^{-3} In the southern latitudes, the maximum abundance of this species was encountered in the thermocline layer of the open ocean stations during summer monsoon (Fig.6.10 & 6.11). As observed in the coastal stations, *E.aculeata* was maximum in the mixed layer during summer monsoon (3054 ind.m^{-3}) and spring intermonsoon (1307 ind.m^{-3}) in the oceanic stations also. *F.bicornis, H.brevirostris, H.inflata, M.stigmatica* were totally absent in the oceanic regions of AS (Table 6.3).

Swarms of *C.dentata* occurred in the AS, throughout the year, but the intensity of swarms varied between seasons. The maximum density of the *C.dentata* swarm (64900 ind.m^{-3}) were observed during the winter monsoon at the oceanic stations of northern latitudes (19°-22°N). Following the seasons from winter monsoon to intermonsoon fall (intermonsoon spring, summer monsoon and intermonsoon fall), the intensity of the swarms (12500, 16000 and 12543 ind.m^{-3} respectively) varied from region (Fig.6.11) to region (off 17°-19°N, 15°&17°N and off 10° &15°N in that order). The horizontal and vertical thickness of the swarm was fairly extensive. The swarms were also observed in the coastal stations of 8, 15 and 19°N during SM, IF and WM, respectively (Fig.6.10).

6.5 Diel vertical migration of Ostracods

There was a nocturnal increase in ostracods abundance at both MLD and thermocline depths, indicating that the organisms were performing diel vertical migration. Comparison with the abundance plots of day and night clearly confirm the DVM of ostracods varying between seasons and depths (Fig 6.8a & b), both in coastal and oceanic regions. The ostracods performed maximum diel vertical migration during summer monsoon followed by winter monsoon and fall Intermonsoon in coastal and oceanic regions, but the migration was found to be maximum in the MLD of oceanic region than in the coastal region

Maximum diel vertical migrations of most of the species were observed during summer monsoon (Table 6.4 &6.5). In the coastal stations, *C.dentata, E.aculeata* were performed DVM during all the seasons. During inter monsoon spring, *E.aculeata* and *C.giesbrechtii* actively migrated to the mixed layer compared to other species. However, their maximum densities in the MLD at night were seen during summer monsoon with a mean abundance of 11614 ind.m^{-3} and 3386 ind.m^{-3}, respectively. *C.acuminata, C.giesbrechtii, C.magna, E.cherchiae, M.rotundata, O.atlantica, O.haddoni, P.procera* also showed high night time abundance during summer monsoon in the MLD of coastal regions (Table.6.4).

In the oceanic region the mean densities of *C.dentata* at night was higher (Table.6.9) during winter monsoon (11897 ind.m^{-3}) followed by summer monsoon (8364 ind.m^{-3}) in the MLD. Night abundance of *E.aculeata* was higher during summer (2843 ind.m^{-3})

followed by spring inter monsoon (3465 ind.m^{-3}). During summer and spring, *C.magna* showed high densities at night whereas *C.giesbrechtii* showed high night density during only spring (Table.6.6, 6.7 & 6.8). Some species like *M.rotundata* migrated up to 300 m-BT layer.

6.6 Statistical Analysis

6.6.1 Community structure indices

The details of average species richness and diversity in the coastal and oceanic stations at different depth layers during various seasons are shown in Table 6.13&6.14. Species richness was maximum during the summer monsoon followed by fall inter monsoon, both in the mixed layer (0.7666 ±0.360) and the thermocline layer (0.962 ±0.635). During FIM, Average species richness in the mixed layer of the coastal region was 0.6723 and with a high spatial variation of 143.33%. Species richness was very low (0.335 ± 0.315) during SIM with high latitudinal variability (85.94%). The number of species increased at the depth of thermocline layer (Table 6.13). In the coastal stations the highest species diversity was seen in the thermocline layer during winter monsoon (2.034±0.220) and summer monsoon (1.601 ±0.473). Species diversity in the mixed layer during WM was more dispersed over stations (C.V. % = 71.36%) with an average value of 1.281(Table. 6.13). On comparing with SIM, FIM and WM, during summer monsoon, a higher stability was observed for the community structure in the mixed layer depth as indicated by low values for spatial variation of all indices.

In the oceanic stations, the species richness was high in the mixed layer during fall (0.247±0.144) and spring (0.086±0.068) inter monsoons (Table 6.14). Species diversity also showed a similar trend as that of species richness. The least species diversity was seen during winter monsoon in the MLD (Table 6.14).During FIM; all the deeper depths except 500-300m strata showed high species richness and diversity. In all the coastal and oceanic stations, there is a gradual increase in species richness to a depth of 1000-500 m. In the oceanic stations, maximum species diversity was seen at 1000-500 m (2.712±0.539) during summer monsoon. Compared to the coastal and oceanic stations, species diversity was high in the oceanic stations. In oceanic waters increase in richness with depth could be observed and also for concentration factor. Not much variation could be observed between seasons for species richness. Species diversity increased with depth in all seasons (Table 6.14).

6.6.2 Cluster Analysis

Similarity between species was studied based on the Bray Curtis similarity index. The data were computed for species in pairs and species were grouped in to clusters of varied similarity levels. For identifying the groups in different clusters, 40% similarity level was taken and the clusters are depicted as a dendrogram using group linkage clustering technique. The similarity index was computed after transforming the observed species abundance (no.m^{-3}) in to standardized 4th root transformed values. In the case of stations the similarity is presented as a non metric multidimensional scaling diagram.

During spring inter monsoon, 5 different clusters were identified (Fig. 6.12a). Notable species in Group 1 were *H.globosa* and *C. imbricata.* Group 2 comprised of *C. dentata* and *E.aculeata.* The members of this group were generally very abundant. Group 3 consisted of *M.rotundata* and *O.atlantica.* The species within this group exhibited similar abundance during this season. Group 4 composed of the species with very low abundance in mixed layer: *P.inermis, P.procera, D.elegans, M.macroprocera,* and *P.parthenoda.* The species included in Group 5 were *C.magna, C.acuminata* and *C.giesbrechtii,* which were restricted in abundance to <10 in the mixed layer of open ocean. In AS during spring inter monsoon 3 main groups of stations were obtained (Fig. 6.12b). Cluster a was the stations located in the northern stations. Cluster b consisted of open ocean stations and coastal stations with comparative high abundance of ostracods. Cluster c comprised of southern stations with dominance of the species,*C.acuminata, C.giesbrechtii*

During summer monsoon, the co occurring species, grouped in to 6 clusters (Fig. 6.13a). Group 1 consisted of *D.discophora* and P *Oblonga.* Group 2 included *H.globosa* and *C.symmetrica.* Group 3 was characterized and included *O.atlantica* and *O.haddoni.* and displayed maximum abundance values in the coastal waters. The Group 4 included *C.dentata, E.aculeata, C.magna, C.acuminata* and *C.giesbrechtii* which displayed maximum density during this season. Group 5 were composed of *A.alata* and *E.cherchiae* and these species were present both in coastal and open ocean waters during summer monsoon. Group 6 included species such as *C.imbricata, H.brevirostris, O.striola, M.kryptophora, M.curta, P.prosadene, O.bispinosa, P.spinifera.* In AS during summer monsoon, 30 stations were studied, for ostracod species distribution. Stations grouped in to 3 main clusters (Fig. 6.13b). Cluster b composed of the southern stations having high abundance of *C.dentata.* Cluster a comprised of most of the oceanic stations having high abundance of *C.dentata* and *E.aculeata.*Cluster c consisted of the northern stations with low abundance of ostracods.

During fall inter monsoon, 7 major groups were obtained (Fig. 6.14a). Species found in Gr.1 were *C.imbricata* and *C.symmetrica*. Group 2 were included *O.haddoni* and *P.procera*. Group 3 were included *P.spinifera, H.bicornis, M.obtusa, O.striola and P.oblonga*. Group 4 were included P.spinirostris, D.elegans,M.acuticosta. Group 5 were included *C.dentata and E.aculeata*, they are the most dominant species during this season. Group 6 were included *A.alata, M.curta, E.cherchiae, O.atlantica, O.bispinosa*. Group 7 *M.kryptophora, M.macroprocera, C.magna, M.rotundata, C.acuminata, C.giesbrechtii,* showed a distribution pattern of comparatively high contribution both in coastal and open waters. During FIM, 34 stations were studied 2 main clusters were obtained, All stations in the cluster a representing northern oceanic stations and southern coastal stations (Fig. 6.14b). Cluster b composed of mainly the northern oceanic stations and two southern coastal stations characterised with high abundance of ostracods. The species mainly composed of *C.dentata, E.aculeata, C.magna, C.giesbrechtii, C.acuminata*.

During winter monsoon, the ostracod species were grouped into 8 clusters. The observed groups were (Fig. 6.15a) Group 1 M.stigmatica, P.porrecta. Group 2 were consist of *E.chechiae, P.oblonga*. Group 3 were *C.acuminata, H.inflata, H.bicornis, O.bispinosa,C.subarcuata and C.symmetrica*. Group 4 were *P.inermis, H.globosa, P.spinifera,* Group 5were *M. curta, P.cophopyga,* Group 6 were *C.dentata, E.aculeata, and* they always showed a biggest contribution to the ostracod biomass. Group 7 were *O.haddoni, C.giesbrechtii, C.magna.*, they were more abundant in coastal waters than open waters. Group 8 were *O.atlantica M.rotundata, P.procera*. During this season, stations were grouped into 3 major clusters. Cluster a comprised of most of the northern stations (Fig. 6.15b), where the swarms of C.dentata was observed. Cluster b and c were southern coastal and oceanic stations respectively.

6.6.3 3 way Analysis of Variance (3 way ANOVA)

In the mixed layer of the coastal regions, no significant difference of ostracod abundance was observed between seasons ($P > 0.05$) day and night ($P > 0.05$) and latitudes ($P > 0.05$). The seasonal changes, day/ night variations and station wise variations were not linked to each other significantly ($P > 0.05$) (Table 6.10a). Seasonal and latitudinal differences were weak in the thermocline layer than in MLD. Similarly D/N variations were observed to be more dependent on seasons in BT-TT than in MLD (Table 6.10a) in the coastal stations of Arabian Sea.

In the open ocean stations, (Table 6.10b), D/N variations were highly significant in MLD ($F_{(1, 18)} = 6.5024$, $P < 0.05$) and thermocline region ($F_{(1, 18)} = 9.1521$, $P < 0.05$). This D/N variations were more pronounced in the thermocline region along with seasonal variations in this layer ($F_{(3, 18)} = 4.473$, $P < 0.05$). Seasonal influence on ostracod abundance in mixed layer depth in the AS was very weak ($P > 0.05$). The seasonal interaction with D/N ($F_{(3, 18)} = 2.7541$, $P < 0.07$, and latitudes ($F_{(18, 18)} = 2.0987$, $P < 0.06$) were highly significant in the thermocline layer (Table 6.10b). In 300m BT stratum, seasonal difference ($F_{(3, 18)} = 4.3076$, $P < 0.05$) as well as diurnal variation ($F_{(1, 18)} = 5.5162$, $P < 0.05$) in the open ocean stations were highly conspicuous. In contrast to 300-BT stratum, seasonal, latitudinal as well as D/N variations were not significant ($P > 0.05$) in 500-300 m stratum.

In 1000-500 m stratum, the ostracod abundance with respect to seasons ($F_{(3,18)} = 3.9784$, $P< 0.05$) and with respect to stations ($F_{(6,\ 18)} = 3.3897$, $P< 0.05$) varied significantly. The season-station interaction (Table 6.10b) was also high ($F_{(18,18)} = 3.3317$, $P < 0.05$)

6.6.4 Two way nested Analysis of Variance (2 way nested ANOVA)

Arabian Sea Coastal stations

Two way nested ANOVA was applied to compare species within seasons viz., spring inter monsoon, summer monsoon, fall inter monsoon and winter monsoon , showed significant differences between species ($F_{(56,\ 317)} = 1.4528$, $P < 0.05$). Applying Gaylor and Hopper conditions for Satterthwaites approximation, was found that between season, differences were not significant ($P > 0.05$ for adjusted ($F_{(3,\ 56)} = 1.0537$, $P > 0.05$), implying that species within season showed an added variance component which remained almost similar in the four seasons in the mixed layer depth (Table.6.11).

Two way nested ANOVA applied to thermocline depth showed an added significant variance component between species ($F_{(73,\ 403)} = 3.00088$, $P < 0.01$). Applying Satterthwaites approximation, based on synthetic denominator, adjusted $F_{(2,\ 72)} = 4.01735$, $P < 0.050$, was highly significant indicating that season wise differences involved a significant added variance along with species difference within seasons (Table 6.11).

Arabian Sea Oceanic stations

Two way nested ANOVA applied to ostracod species in mixed layer depth in the open ocean resulted in highly significant differences among species ($F_{(6,403)} = 2.91297$, $P < 0.05$) indicating a significant added variance component due to species. Applying Satterthwaites approximation it was observed that seasonal difference was only due to sampling fluctuations {($P > 0.05$), adjusted $F_{(3, 61)} = 0.9114$, $P>0.05$)}. In the thermocline layer this analysis resulted in significantly high species wise differences $F_{(75, 474)} = 1.85099$, $P<0.010$). But no significant added variance component due to seasons was observed (adjusted $F_{(3, 75)} = 0.8275$, $P>0.05$) (Table 6.12). In 300 m-BT stratum significant added variance component due to seasons (adjusted $F_{(3, 67)} = 1.3247$, $P<0.28$) was observed, but among ostracod species an inherent significant variance component was observed $F_{(65, 374)} = 2.6788$, $P<0.01$) (Table 6.12). In the 300-500 m, depth stratum same pattern of variance was observed, among species in different seasons ($F_{(77, 431)} = 1.5408$, $P < 0.01$) an added significant variance component was evident but seasonal differences were only hypothecated (adjusted F (3, 77) = 0.2590, $P > 0.05$) (Table 6.12). In the 1000-500 m depth stratum, a significant species difference was noticed between different seasons ($F_{(95, 528)} = 1.42$, $P < 0.05$), but between seasons, the difference in species abundance was significant only at a lower level of confidence ($F_{(3, 98)} = 1.6279$, $P<0.19$) (Table 6.12).

6.7 Discussion

Ostracods contributed significantly to the biomass of zooplankton in the Arabian Sea with unusual high density due to swarming. However, due to the small size, their abundance is often underestimated. In the Arabian Sea, studies on planktonic ostracods received very little attention. George (1975, 1979); James (1972, 1973); George and Nair, (1980); Mathew *et al.*, (1980); Nair and Madupratap, (1984), Mathew *et al.*, (1996) have published papers on planktonic ostracods in the Northern Indian Ocean, but no detailed attempt has hitherto been made to understand the seasonal difference of ostracod community and their relation to the hydrographical and productivity variations. About 33 species were recorded for the first time within the ostracods community from this area (George *et al.*, 1979). In warmer oceans, ostracods reach peak numbers in the upper 500 m, contributing to total biomass except for certain coastal tropical regions where they become really abundant. Their population generally decreases with depth. In this study *C.dentata* was the dominant species occured in the Arabian Sea. George, (1968) recorded 33 species of ostracods from Indian Ocean belonging to 18 genera. *Euconchoecia aculeata* was the most abundant species in the northern Indian Ocean. However, for the Arabian Sea alone *Cypridina dentata* was the most abundant species (George, 1968). In this study, the distribution of this species varied between seasons and showed coastal open ocean variation in their abundances. *C. dentata* was reported mainly in the neritic waters of AS and off the west coast of India. *C. dentata* often forms swarms in the Arabian Sea and high density of this species was also reported from Laccadive Seas (George, 1979). Off the Maharashtra coast the species coexisted along with swarms of chaetognaths, *Sagitta enflata* (Nair, 1978). Even though *C.dentata* could tolerate a salinity range of 35-36, they were not frequently recorded from the Bay of Bengal and equatorial regions of the Indian Ocean (George & Nair, 1980). Most of the ostracods species enjoy a wide distribution and are cosmopoitan in Atlantic, Pacific and Indian Oceans. Many of the ostracod species like *Euconchoecia aculeata, Halocypris brevirostris, Conchoecia* *giesbrechti, Metaconchoecia rotundata, Orthoconchoecia striola* and *Spinoecia porrecta* were better represented in the upper 200 m watercolumn as observed earlier (George, 1968). *C. dentata* showed accumulation above thermocline and agreed with the observation made by Madhupratap *et al.*, (1981). Distribution of *Orthoconchoecia atlantica* did not seem to be influenced by the thermocline. *Discoconchoecia elegans, D. discophora, P. procera, P. decipiens, Conchoecetta acuminata, Orthoconchoecia bispinosa, P. parthenoda, Conchoecia magna* and *Conchoecilla daphnoides* were the other species represented in low numbers in the Arabian Sea. *P.spinirostris* is an epipelagic species that migrates in to the mesopelagic zone especially during spring while the other species *Porroecia porrecta, Conchoecia magna, Microconchoecia curta, M.echinulata, P. procera and Discoconchoecia elegans* are mesopelagic species that migrate in the epipelagic zone (Angel,1993). *Metaconchoecia rotundata* was also abundant in the mesopelagic zone irrespective of all seasons, since it is a typical mesopelagic species (Angel, 1993)

The second highest abundance of ostracods was observed during the winter season due to the highest contribution of juveniles of *C.dentata*, which was in contrast with the higher contribution of adults during summer. Also the females were generally about 40% more abundant than males during winter. In majority of the species, females outnumbered males and was the case with 'Discovery material' collected from the NE Atlantic and the specimens from the Adriatic Sea (Angel, 1977., Brautovic, 1998). *D.elegans* and C. *daphnoides* occurred in maximum numbers in spring inter monsoon. In this study, *M.curta* was seen in most of the coastal stations throughout the year. According to Angel (1977), *M.curta* occurs throughout the year and appears to have a non- seasonal life cycle.

Day and night variation in abundance revealed a pronounced vertical migration during summer monsoon and winter monsoon and the DVM was restricted to some of the species. Nair *et al.,* (1973) though observed night time abundance of ostracods in the Indian Ocean, in general, a day night variation was not established in the Arabian Sea. Mathew *et al.,* (1996), noticed high abundance of ostracods at night during the end of summer monsoon, confirming the vertical migration of ostracods.

The maximum density of the *C.dentata* swarm (64900 ind.m^{-3}) was observed during the winter monsoon at the oceanic stations of northern latitudes (19°-22°N). From winter monsoon through fall intermonsoon (spring intermonsoon, summer monsoon and fall intermonsoon), the intensity of the swarms varied from region to region (off 17°-19°N, 15°&17°N and off 10° &15°N in that order). The horizontal and vertical thickness of the swarm was fairly extensive. The swarms were also observed in the coastal stations of 8, 15 and 19°N during SM, IF and WM, respectively. The vertical distribution of the swarm extended up to 200 m. The response of the mesozooplankton to the winter conditions of the northern Arabian sea has been highlighted by Madhupratap *et.al.,*(1996). The mesozooplankton standing stock was high in the northern regions of the Arabian Sea during winter monsoon. Earlier studies have shown that the north and northwestern Arabian Sea is 4-10 times richer in zooplankton biomass (280ml/100m^3) compared to the entire Indian Ocean (Paulinose and Aravindhakshan, 1977). An increase in biomass during night at some of the northern stations was mostly attributable to the higher density of ostracods. Among the zooplankton, copepods generally dominated numerically, but in the northern latitudes spectacular swarms of ostracods replaced the dominance of copepods. These swarms were generally confined to the mixed layer or some times up to the bottom of the thermocline, the latter mostly during day time (Madupratap. *et al*, 2002). Swarms of ostracods are frequent in the northern areas of the Arabian Sea during winter monsoon and summer monsoon (Kumary and Achuthankutty, 1989; Madhupratap *et al*., 1992). This may be due to the swarming behaviour of *C. dentata*. George *et. al.* (1976) has reported that *C.dentata* occurs mainly in the neritic waters and off the south west coast of India, becoming sparse beyond the edge of the continental shelf in the AS. However in the present study, this species was recorded from both oceanic and coastal regions of northern Arabian Sea. From this it can be inferred that the species dominance is not due to the coastal oceanic regimes, but due to some other factors influencing the distribution. Most of the samples had gravid females with eggs and juveniles, indicating that propagation has been continuing in the area. The incidences of dense patches of juveniles also suggest that the period of heavy spawning is of long duration. It has been observed that the swarming of the ostracods have direct relation with the physico chemical factors such as temperature, salinity, DO, Nutrients, light and water current (Fasham&Angel, 1975,). George *et al.*, (1969) reported the abundance of ostracods during winter monsoon in the Indian ocean which could largely be due to the result of swarming of *Cypridina dentata* in the Arabian sea.

Distribution of *Cypridina dentata* was very much influenced by the hydrographic conditions of the prevailing region. For instance, the hydrographic conditions prevailing in the Red sea (salinity~36.7-40.5, and temperature 21.9 - 29.5°C) may not be congenial for all the species of ostracods (Deevey, G.B, 1968; Kimor,1973), occurring in the Arabian Sea. The hot saline waters of Red Sea and perhaps other physical and chemical factors are a barrier to the successful maintenance of many ostracod species especially *C. dentata*. Various studies have updated the hydrography and zooplankton standing stock of northern Arabian Sea Kumar& Prasad (1996), Paulinose.and Aravindhakshan (1977).

The swarming of ostracods (*C. dentata*) also shows affinity to the Arabian Sea High Saline Water mass (ASHSW) to their distribution. The ASHSW has its origin in the northern Arabian Sea, and is known to extend southward, flowing along the south west coast (Kumar&Prasad 1996 and Qasim ,1982). It is characterised by high Dissolved oxygen (~200 μM) and nutrient levels (NO_3 ~3.5 μM).Water masses with particular species assemblages cannot be traced by physical properties only but also with biological combinations. This useful fact indicates that those pelagic animals which are confined to the water masses are defined by the temperature - salinity relationship. Literature related to the influence of water mass characteristics on ostracods are rather scarce. Fasham and Angel (1975) reported the affinity of planktonic ostracods to water masses in the North East Atlantic. The zoogeographic ranges of the individual species, do not clearly indicate water mass distribution, but the geographic distribution of the communities corresponds to some extent to water mass. (Correge, 1993, Angel and Fasham, 1975). Aggregations of organisms based on the environmental relations are available, such as amphipod swarm in the Campbell bay (Nair, 1981) and swarms of pteropod *Cresis acicula* (Goswami, 1978).Cypridiniforms have evolved ecophysiologically and behaviorally to cope with the environmental constraints and this is thought to be manifested in the present environment. From this observation it becomes evident that this species also can be used for such study.

The population density of this species was very high at the mixed layer in the northern AS (Fig.6.7) and it was confined to the thermocline layer in the south AS. During winter monsoon (November-February) the winds in the coastal region off western India are generally equatorward with monthly mean wind speed of approximately 3 m/s (Hastenrath and Lamb, 1979). Formation of major water mass in the Arabian Sea takes place during November – January and the mechanism (Fig.6.6) is that the cool dry continental air brought in to the northern Arabian Sea by the prevailing northeast trade winds enhances evaporation resulting in high saline water mass at surface (35.2 to 36.8). During winter, the winter cooling process prevails over the northern AS, which provides convective mixing, resulting in high biological production. Waters north of 15°N, experiences cooling and densification (Prasannakumar *et al.*, Banse *et al,* 1986; Madupratap et al.,1996a), and this lowered thermal and high saline condition can be considered as an optimal condition for the proliferation of *C.dentata*. During this study the winter cooling generated chlorophyll a and primary production with values as high as 58.77 mgm^{-2} and 1394 mg C $m^{-2}day^{-1}$at the northern most latitude. This high production in these latitudes also might influence the aggregation. The seasonal distribution of the swarming of this species is clearly seen in Figure 6.7. Samples of *C.dentata* are mainly contributed by juveniles and females. Females with eggs in the marsupium were present in the samples collected; suggesting that species aggregation is making a spawning behaviour. In ostracods, the spawning period and the place are closely related to ecologically favorable regions (Fasham &. Angel, 1975, Nair, 1978). Ostracods are filter feeders and the food availability in the water column accelerates the lifecycle.

C.dentata has shown some dependence with the ASHSW, and the species distribution clearly indicates its association corresponding with the spreading of ASHSW. The core of the ASHSW was seen below the surface in the north, deepens towards the south, and corresponded with that of the distribution of species. During summer monsoon, the distribution of the *C.dentata* was in high abundances in the oceanic stations off 15° to 10°N. During this period, detailed analysis revealed that low temperature and high saline water were confined in south west coast of India and extent northward up to 17°N. During fall intermonsoon, low temperature and high saline water exist in the upper layers of the AS. *Cypridina* spp. frequently swarm in the AS during this season as reported from off cochin (George,1977) and off Maharashtra coast where the species co-existed with swarms of chaetognaths *Sagitta enflata* (Nair,1978). The low temperature and high saline waters in the upper surface layers were congenial for their swarming. In addition, following the summer monsoon and fall intermonsoon the higher primary production in the southern AS also provided an impetus for proliferation of this species.

Ostracods are distributed from epipelagic to the abyssopelagic depths and play an important role primarily as detritivores (Angel,1983), but can also be herbivores and carnivores (Hopkins, 1985; Hopkins and Torres, 1988, Vannier *et al.*, 1998). Results suggest that some of the planktonic ostracods in the AS, mostly in the oceanic waters could be predominantly detritivores, where as the species like *C,dentata*, *E.aculeata* and those flourishing at the surface are herbivores. The highest abundance of planktonic ostracods during the summer might be related to the minimum occurrence of the groups of the potential predators. (Gelatinous and semi gelatinous zooplankton). Nair *et a., l*(1978) recorded the co existence of swarms of *C.dentata* with Chaetognatha. Batistic *et al.*,

(2003) found ostracods in the gut contents of Chaetognatha during summer season in the South Adriatic Sea. During summer monsoon in the southern coastal AS, after the upwelling event there was an increase in the herbivorous community followed by carnivorous organism (Madhupratap and Haridas, 1990). This coincided almost with the total absence of *P.inermis* and *D.elegans* during this period. Moreover, it seems that predation by hydromedusae might have caused significant decrease in ostracods abundance (Matsakis & Conover,1991); gelatinous predators such as hydromedusae, siphonophores and ctenophores can strongly reduce ostracods populations by more than 20% per day.

Statistical results also revealed the significant difference of ostracod abundance between seasons, day and night and latitudes prominently at oceanic stations than the coastal stations. Among ostracod species, the seasonal difference was not significant in the mixed layer of coastal stations, but in thermocline and deeper depths the differences were significant. These seasonal differences are due to the seasonal hydrographic changes and the associated productivity patterns. Diversity of ostracods was high in the oceanic stations and in deeper depth layers. In the marine environment higher diversity is sustained in the oceanic realm where more stable conditions occur allowing ideal conditions to attain a high degree of equilibrium and niche separation (Nair, *et al.*, 1981). Depth related increase in diversity from coastal to oceanic locations and surface to deeper waters are common pattern in ostracod communities (Angel, 1984; Angel, 2007)

The present results also suggest that except for top down control of ostracods populations, among environmental factors, the salinity and temperature and the productivity patterns seems to be most important for the distribution of planktonic ostracods. In the AS higher species diversity of ostracods were seen in the oceanic and deeper stratas than coastal stations. Surface dwelling species of ostracods in the AS were highly depending on the phytoplankton biomass and the bathypelagic detritivorous species were also depended on the surface production. In this study, an attempt has been made to understand the factors influencing the swarming of *C. dentata*. The hydrographic condition of the swarming area was marked by high saline watermasses (>36.2), having relatively low temperature (<26°C). This environment appears to be the most favorable one facilitating rapid propagation. The chlorophyll *a* concentration (during winter monsoon, intermonsoon spring, summer monsoon and intermonsoon fall, respectively) although did not directly influence the propagation of this species, it had an influence on the increased density of the swarming population. From this study it is concluded that swarms of *C.dentata* occur in high saline waters (>36.0 psu) having low temperature (<26°C) and propose that these swarms are invariably an indication of the presence of the Arabian high saline water mass. High number of species newly recorded in this study as compared to the previous study (during IIOE) suggests the possibility of the existence of the even higher biodiversity in deeper waters of the Northern Arabian Sea.

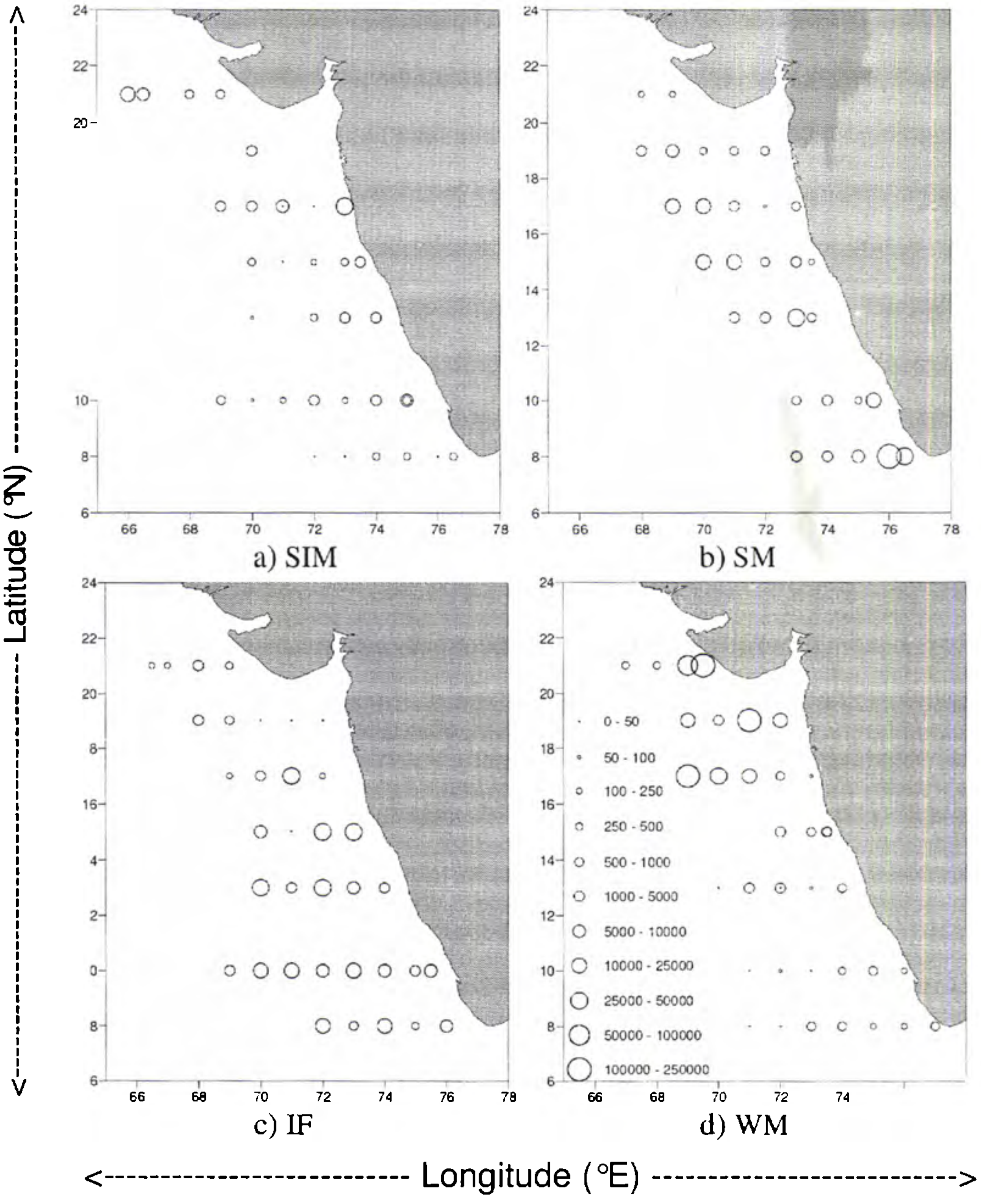
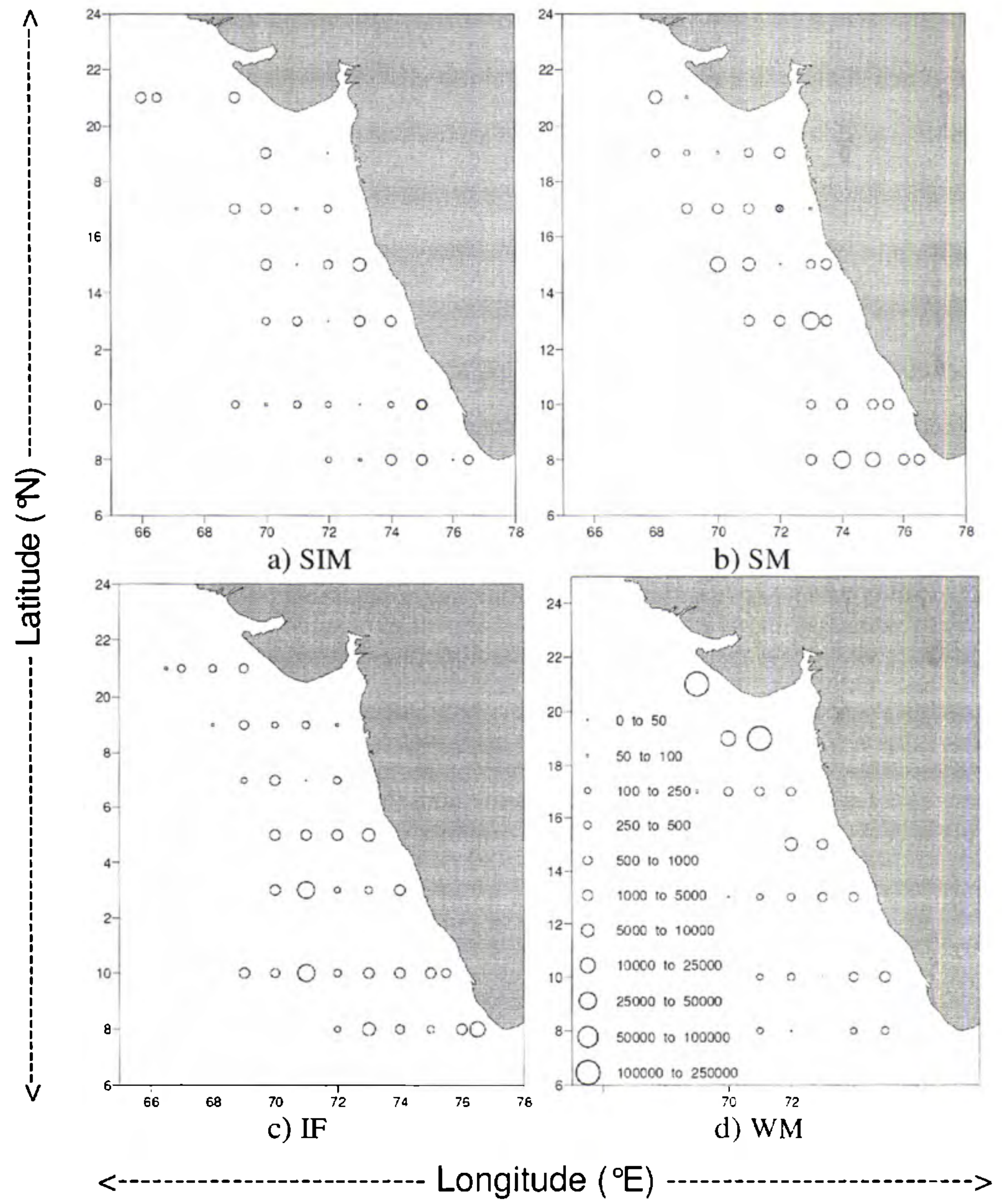


Fig.6.1 Spatial distribution of ostracod abundance in the mixed Layer of the Arabian Sea during different seasons a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.



a) SIM

b) SM

c) IF

d) WM

Fig.6.2 Spatial distribution of ostracod abundance in the Thermocline layer of the Arabian Sea during different seasons a) Spring inter monsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.

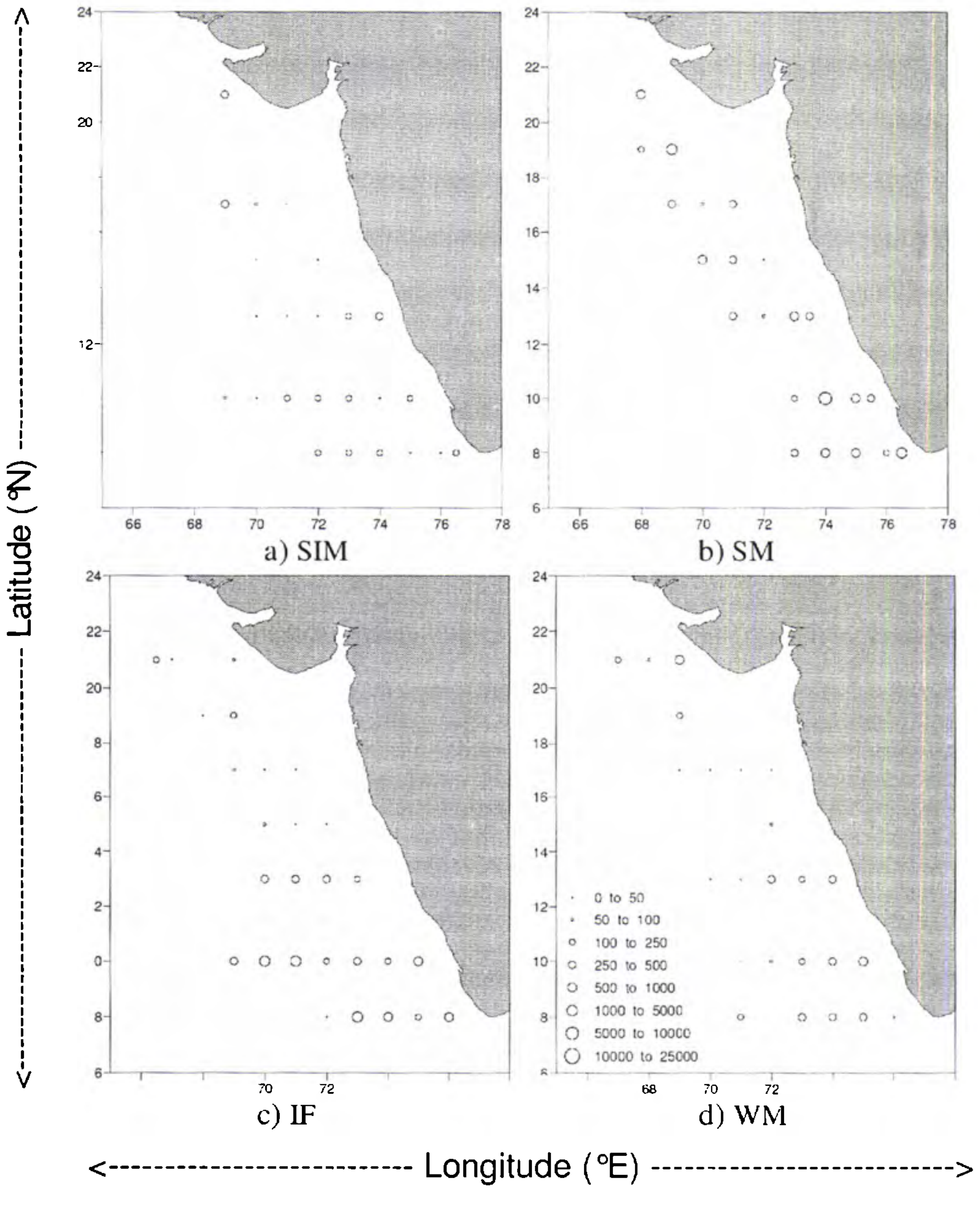


Fig.6.3 Spatial distribution of ostracod abundance in the 300-BT layer of the Arabian Sea during different seasons a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.

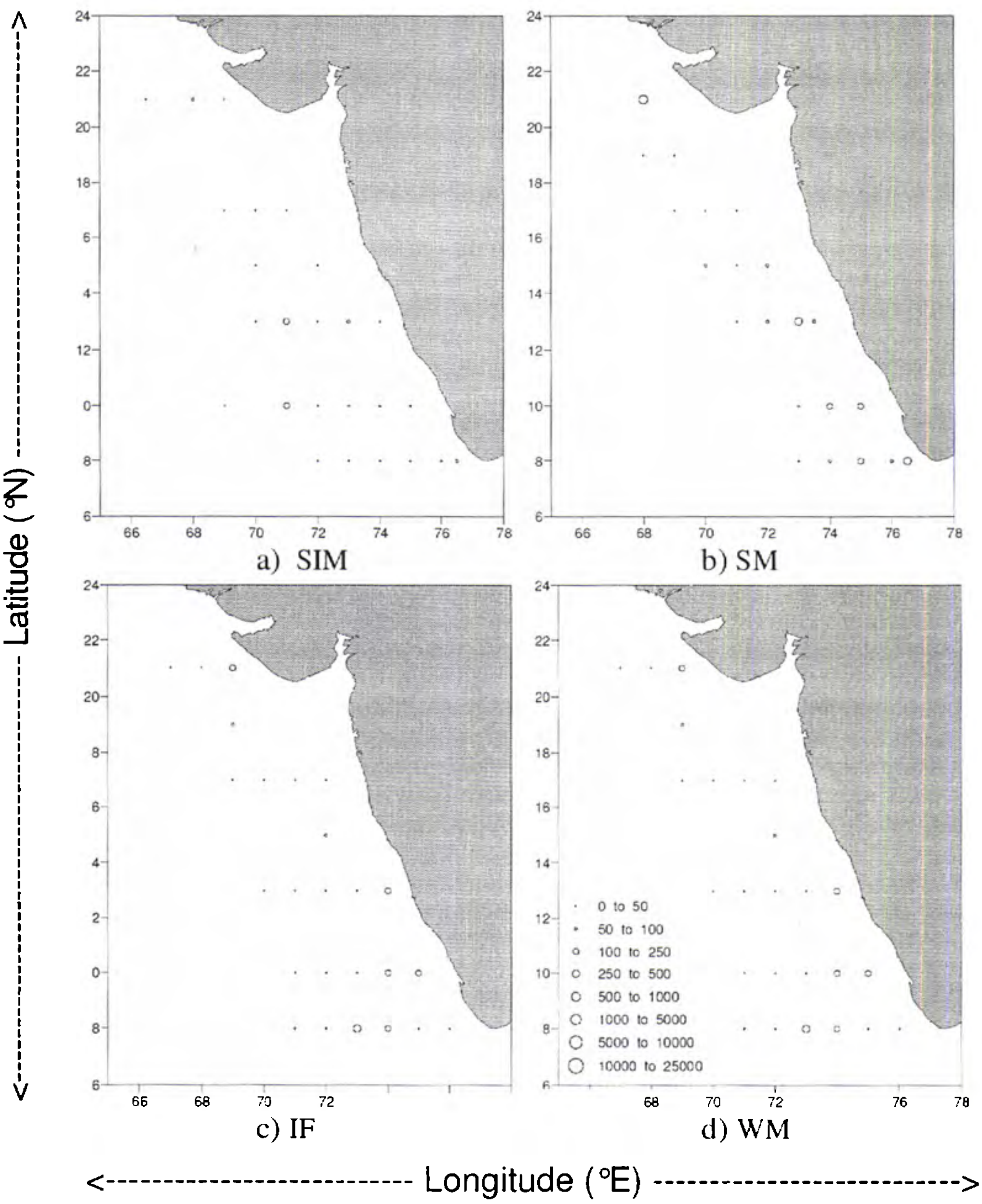

a) SIM
b) SM
c) IF
d) WM

Fig.6.4 Spatial distribution of ostracod abundance in the 500-300 layer of the Arabian Sea during different seasons a) Spring inter monsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon

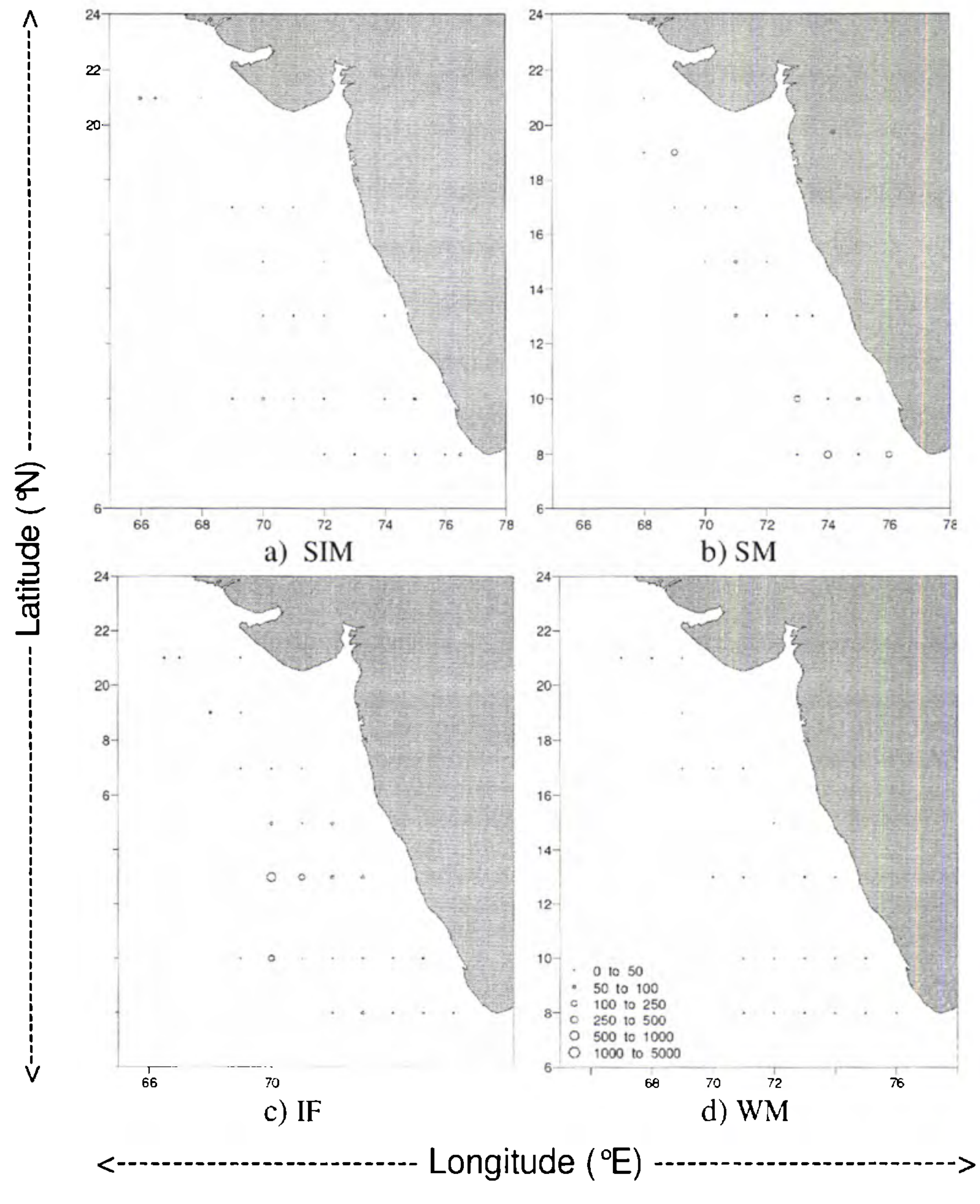


Fig.6.5 Spatial distribution of ostracod abundance in the 1000-500 layer of the Arabian Sea during different seasons a) Spring inter monsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon

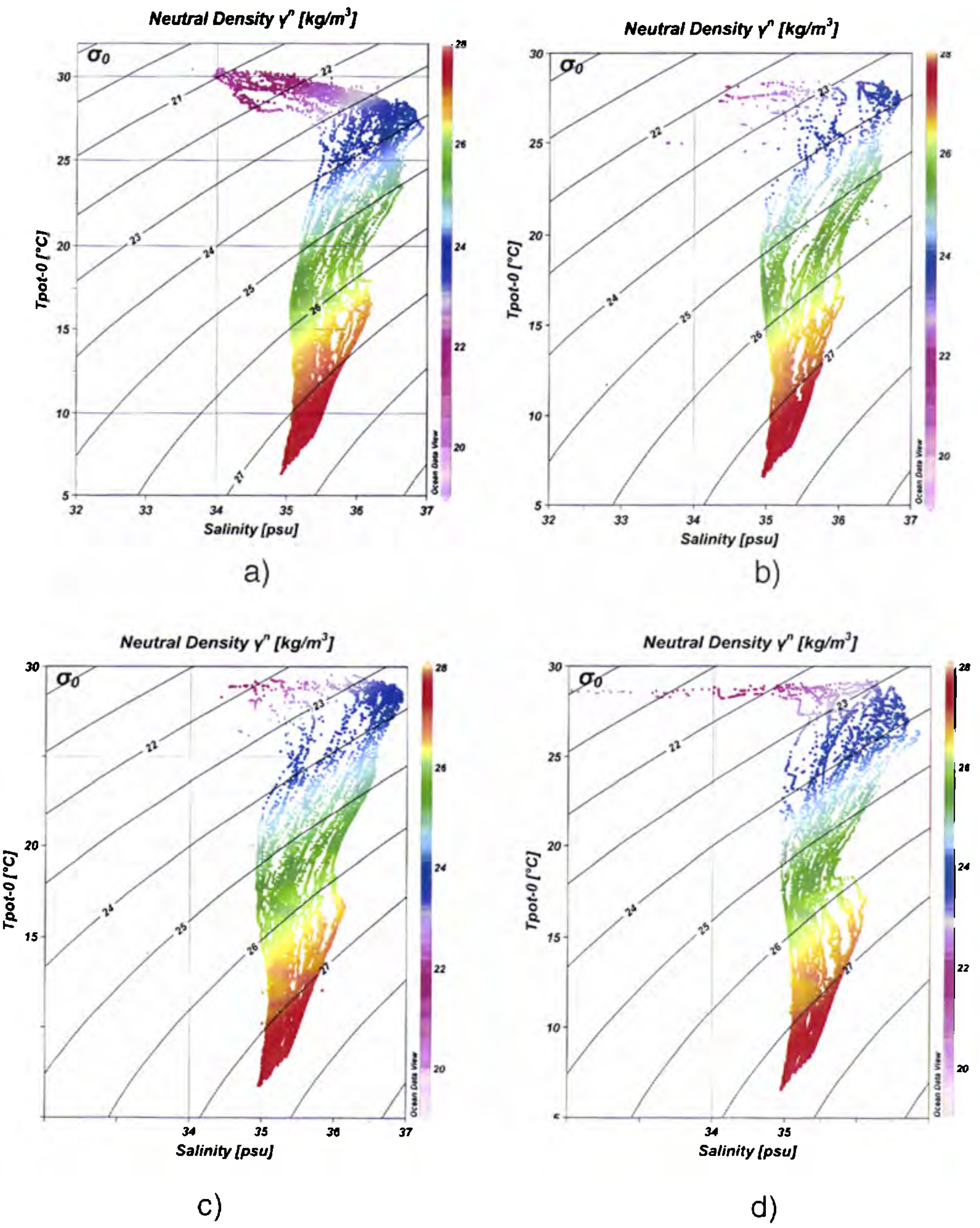


Fig.6.6 TS daigram showing the water masses (ASHSW, PGW and RSW) of the western Arabian Sea during different seasons a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.

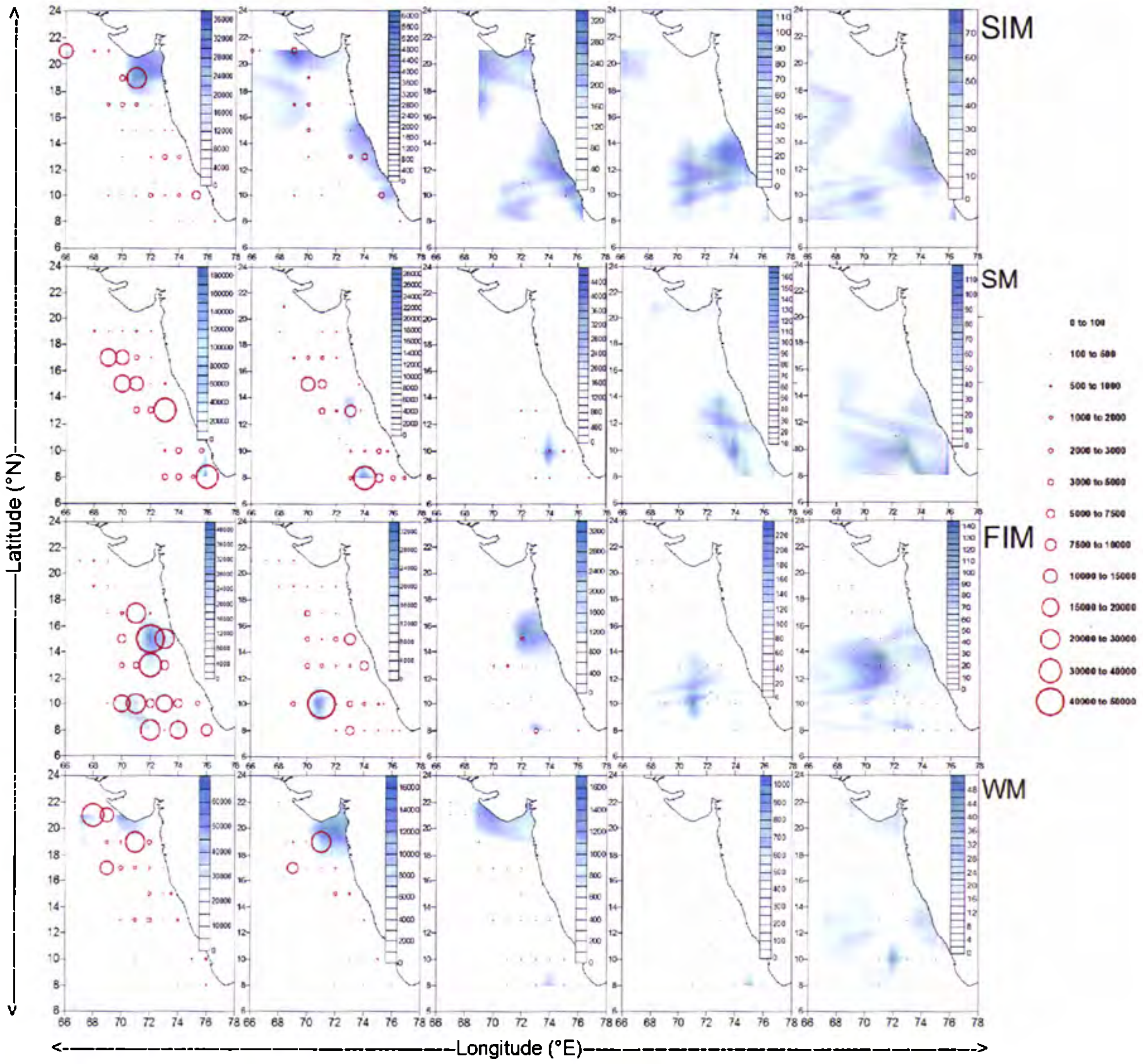


Fig.6.7 Mean abundance of *Cypridina dentata* (bubble) over total ostacods abundance (shaded) during different seasons and depth strata a) Spring intermonsoon b) Summer monsoon c) Fall intermonsoon d) Winter monsoon.

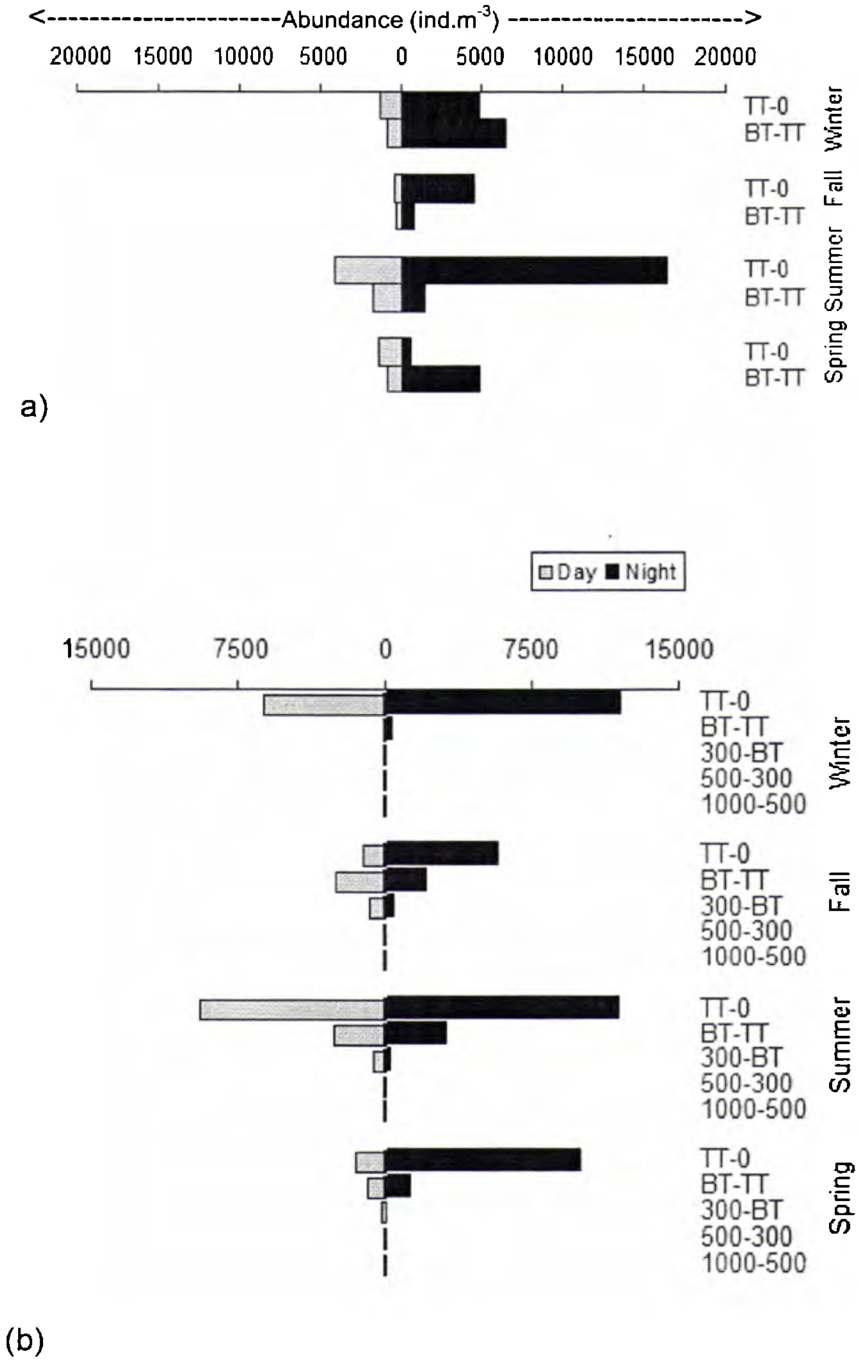


Fig. 6.8 Day night variation of ostracods in the a) Coastal and b) Oceanic stations of the Arabian Sea during different seasons.

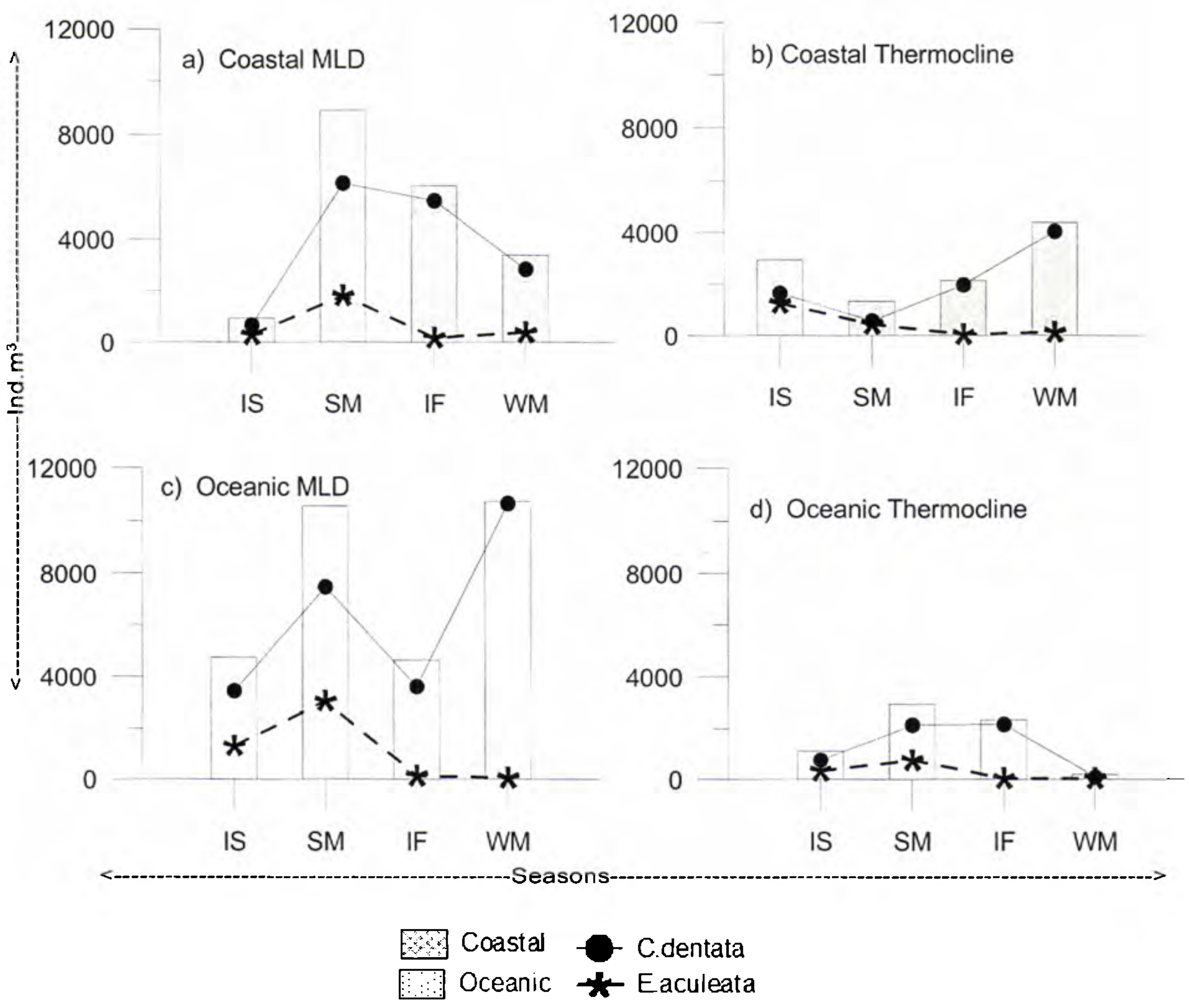


Fig.6.9 Distribution of *C.dentata* and *E.aculeata* in the coastal (a)Mixed layer (b)Thermocline and oceanic (c) Mixed layer (d)Thermocline during different seasons of the Arabian Sea.

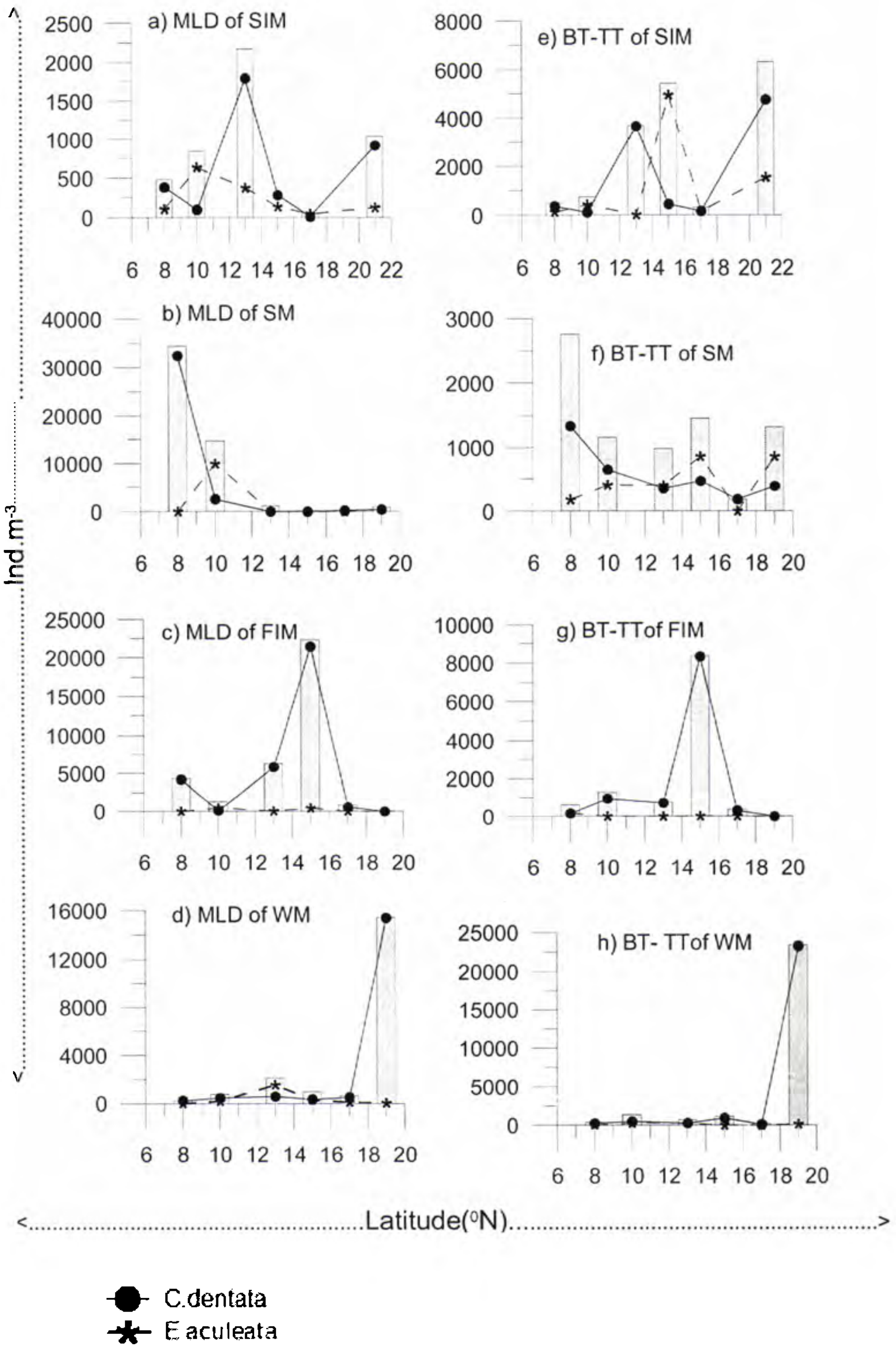


Fig. 6.10 Distribution of *C.dentata* and *E.aculeata* in the different latitudes of the coastal stations of the Arabian Sea (a) to (d) Mixed layer and (e) to (h) Thermocline.

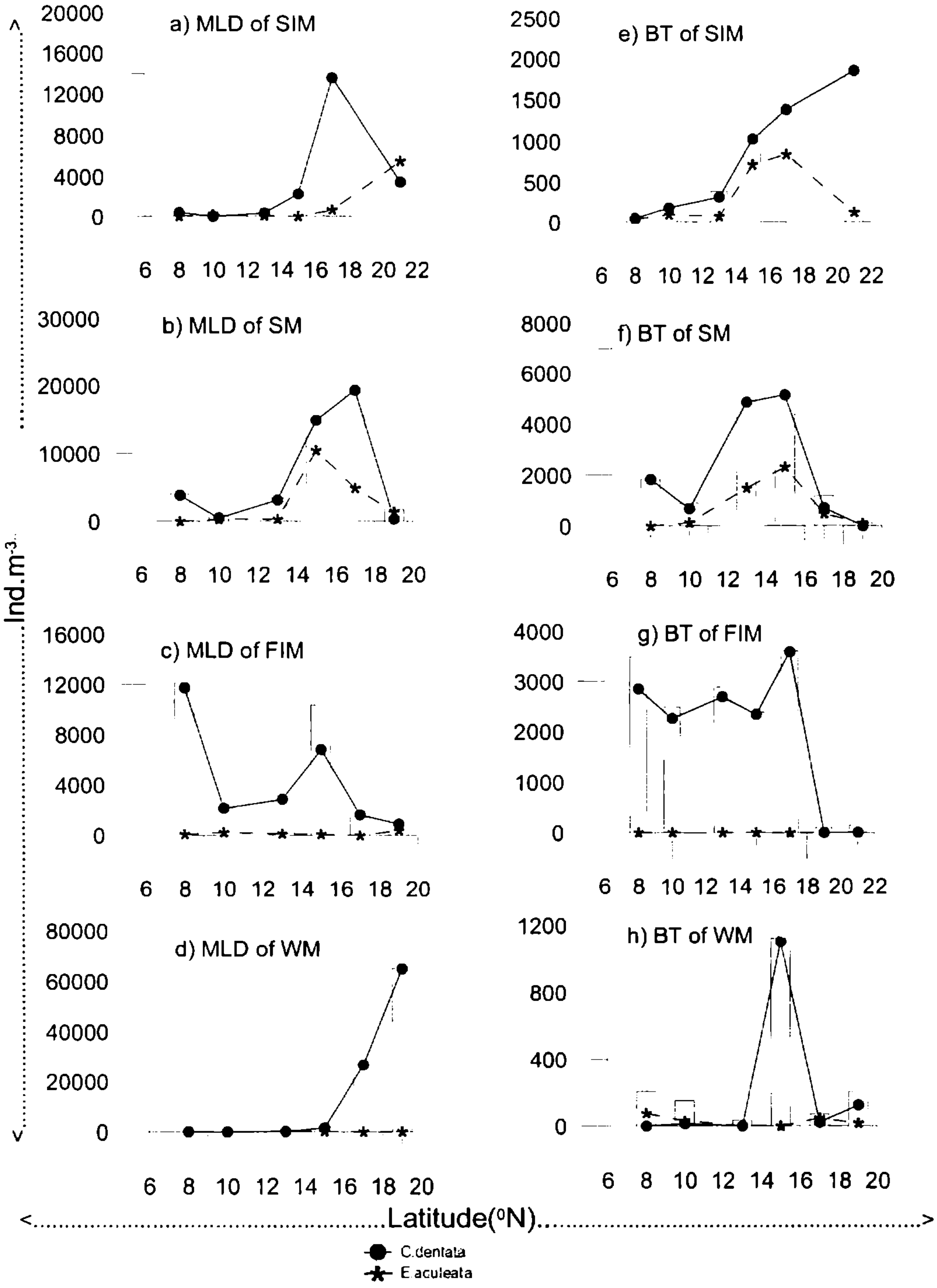


Fig. 6.11 Distribution of *C.dentata* and *E.aculeata* in the different latitudes of the oceanic stations of the Arabian Sea (a) to (d) Mixed layer and (e) to (h) Thermocline.

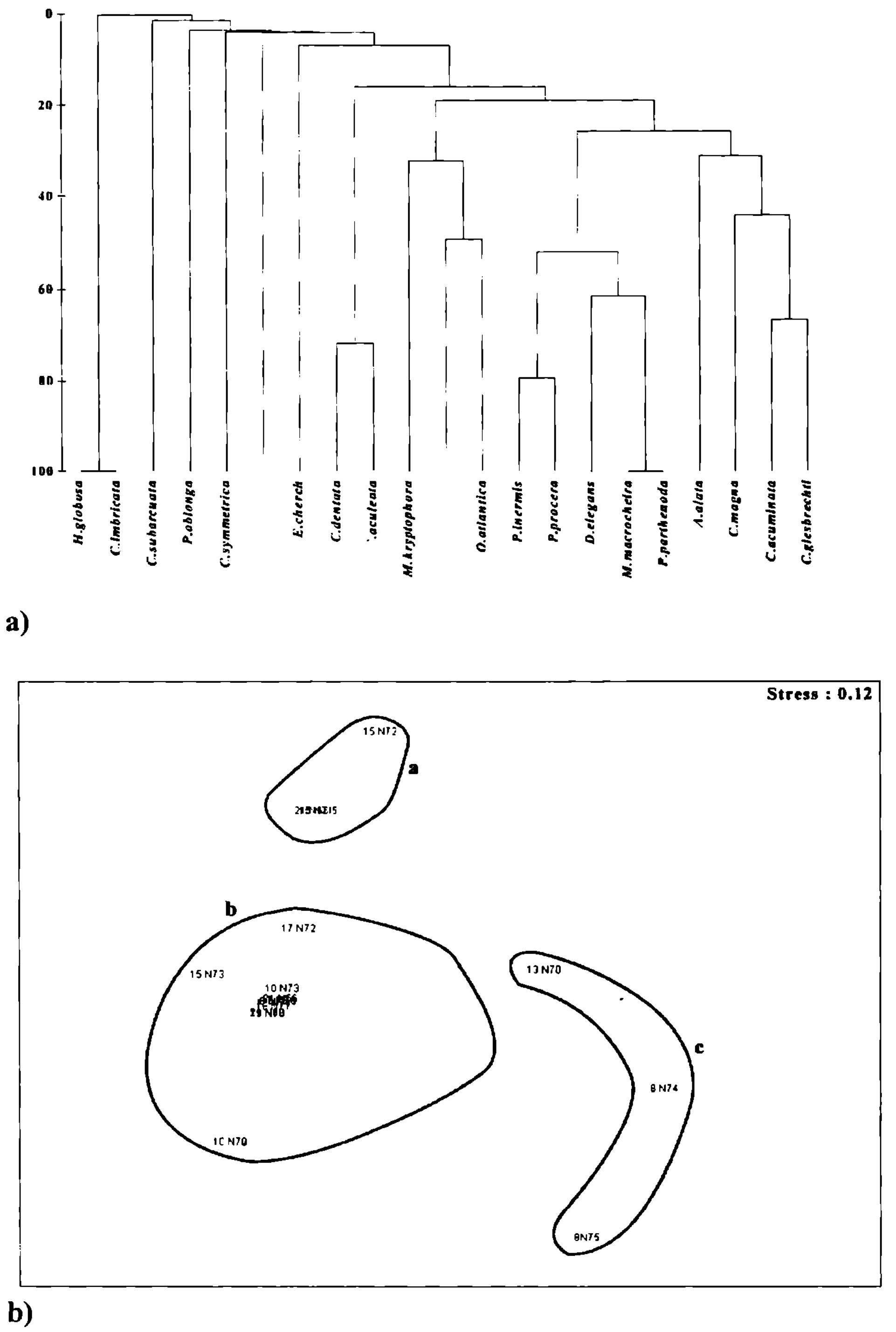


Fig6.12 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the AS during spring intermonsoon.

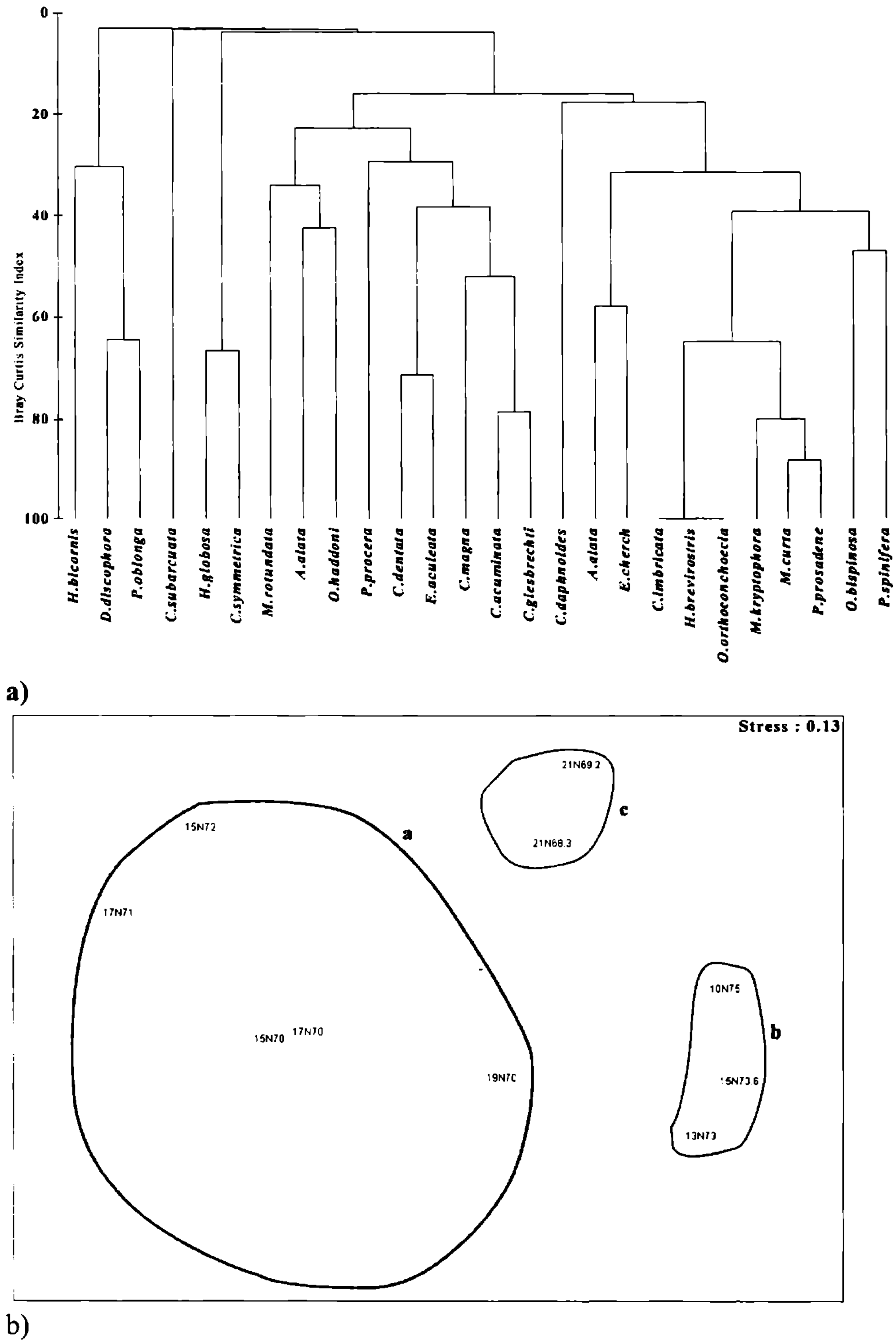


Fig. 6. (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the AS during during summer monsoon.

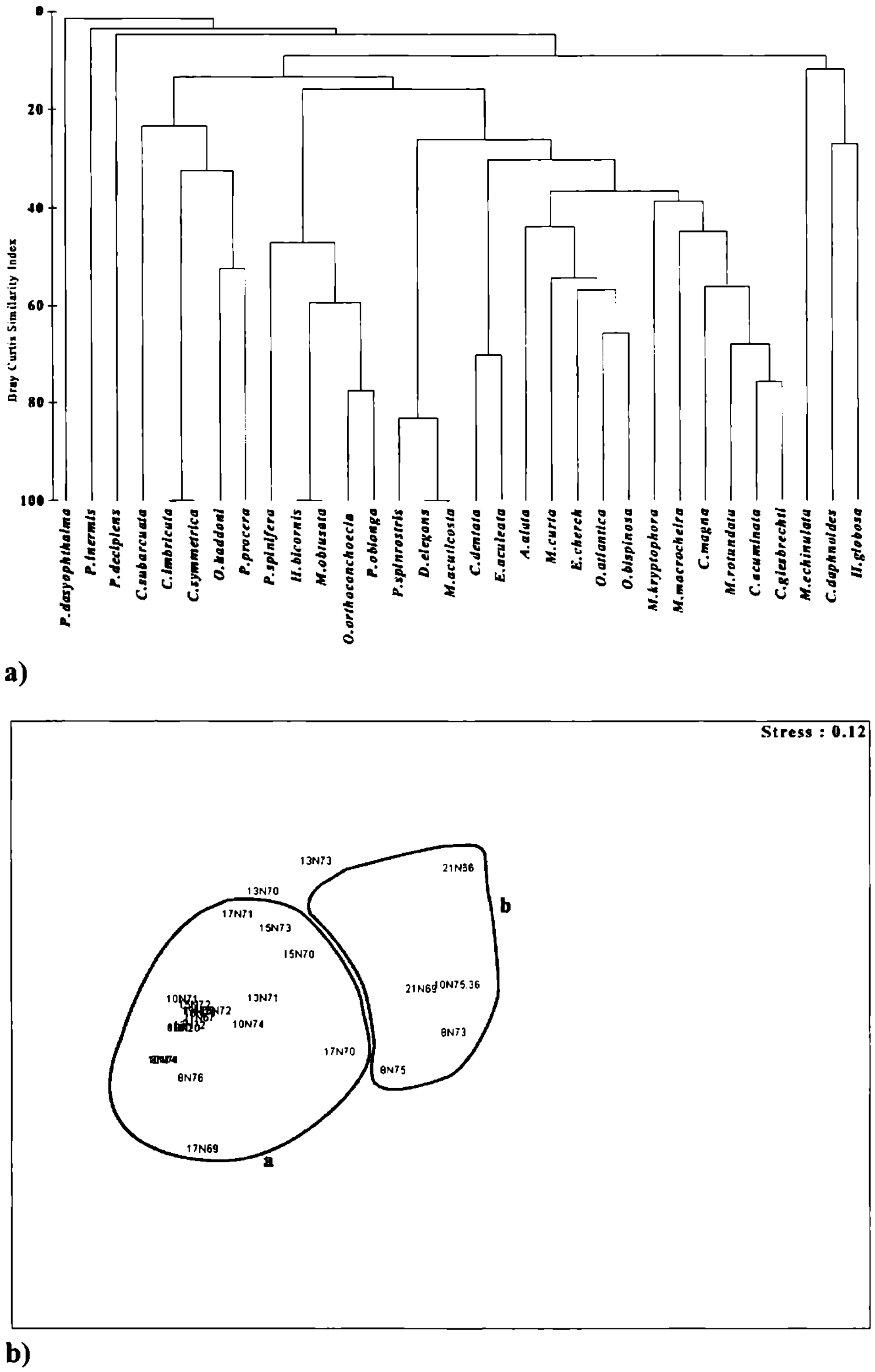


Fig. 6.13 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the AS during during fall intermonsoon.

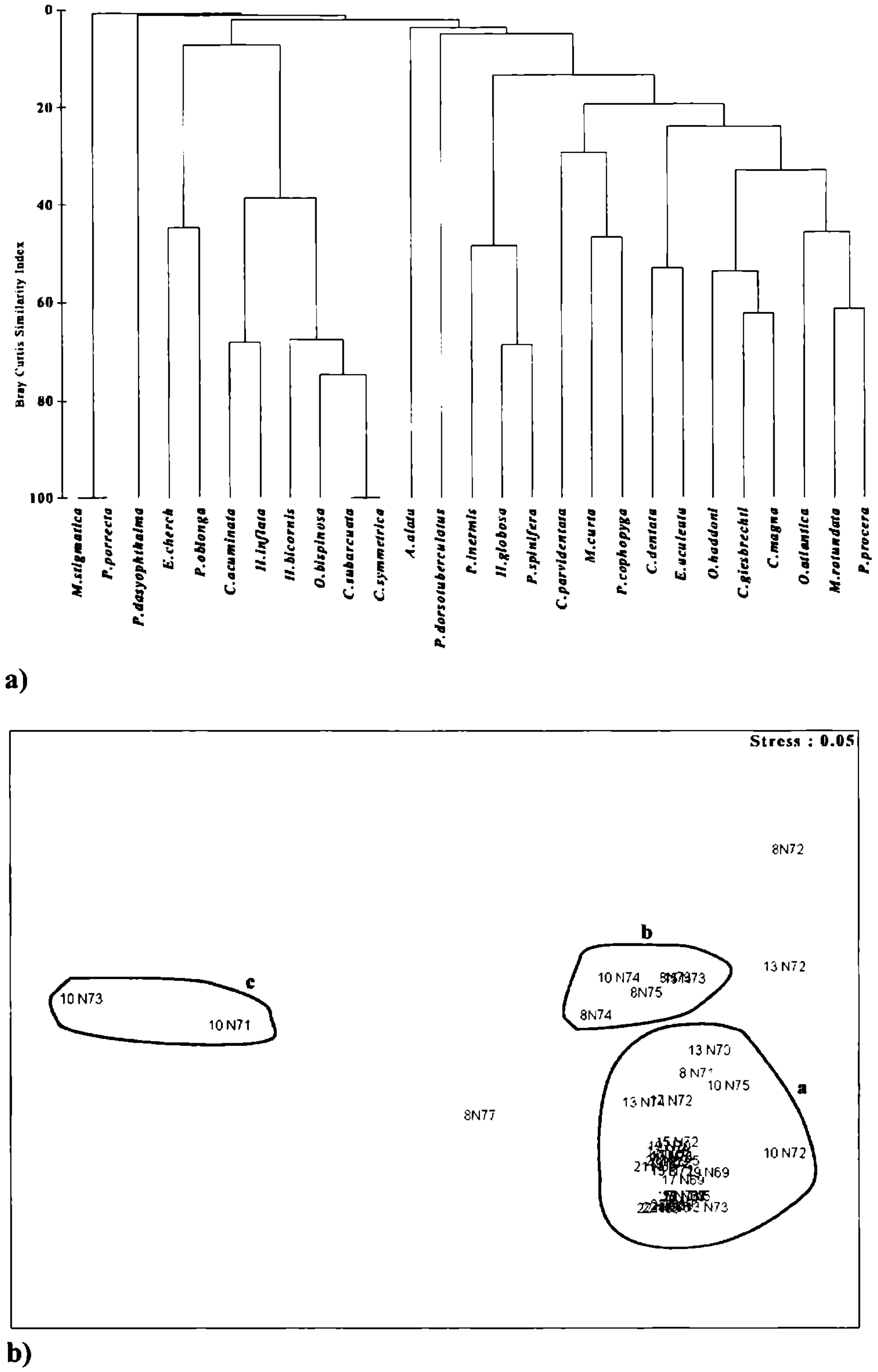
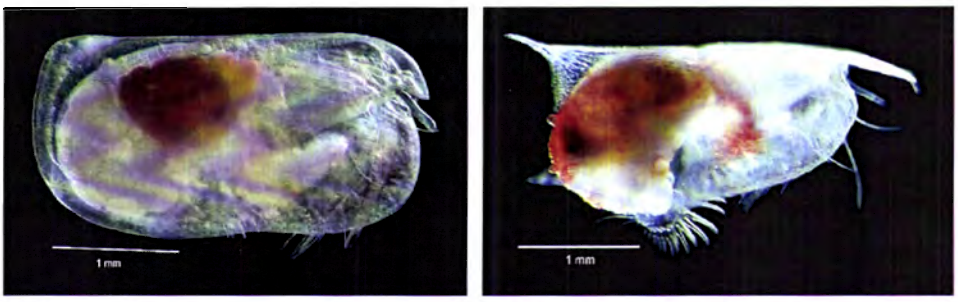
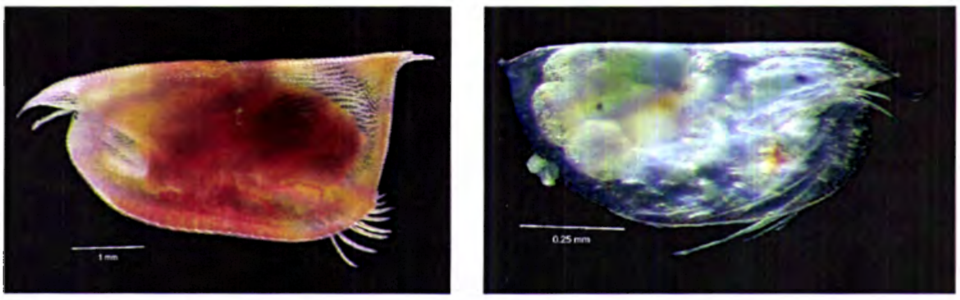


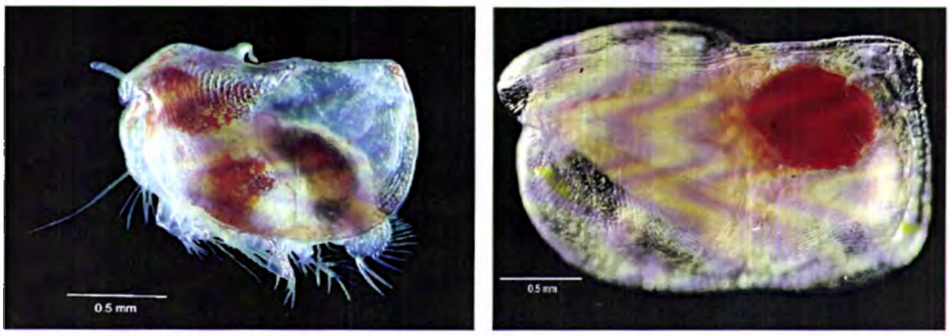
Fig. 6.13 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the AS during during winter monsoon.



a)*Conchoecia macrocheira* b)*Conchoecissa imbricata*



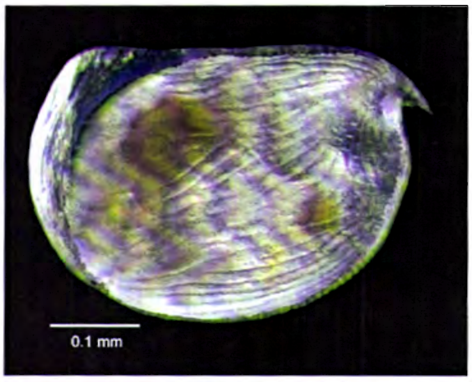
c)*Conchoecissa plinthina* d)*Euconchoecia chierchiae*



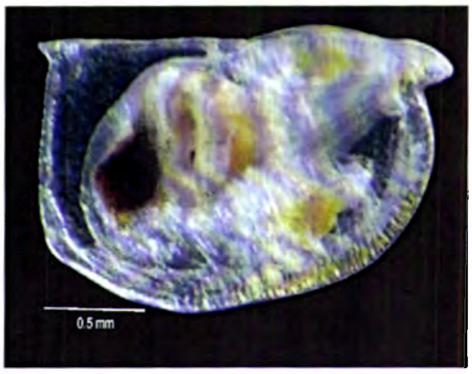
e)*Fellia bicornis* f)*Loricoecia loricata*

g)*Conchoecilla daphnoides*

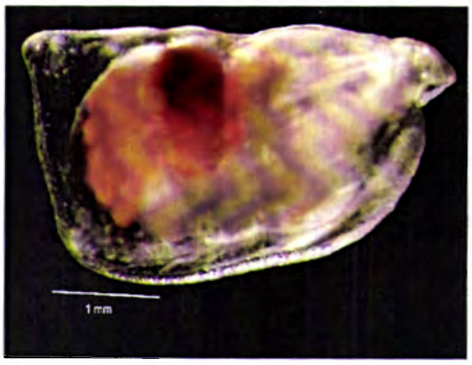
Plate 6.1 (a) – (g) Photographs of some of the planktonic ostracods obtained from the Arabian Sea and Bay of Bengal



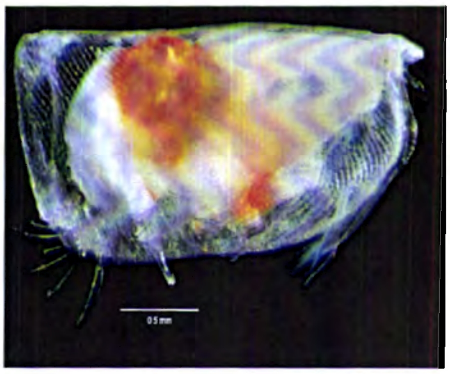
h) Mikroconchoecia echinulata



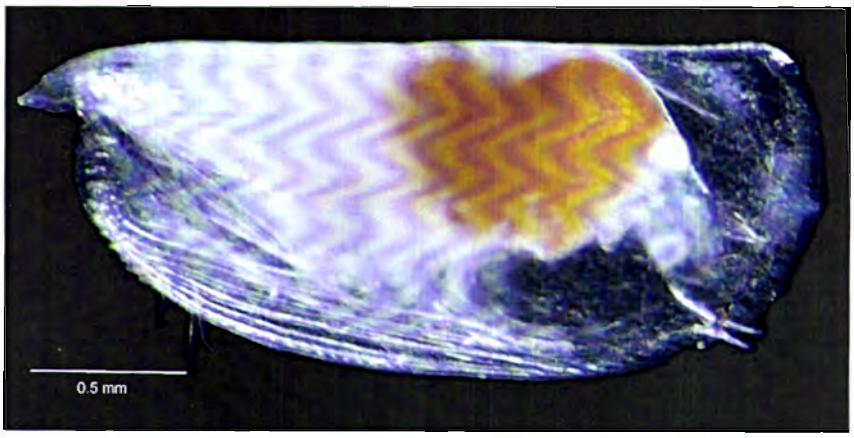
i)Orthoconchoecia bispinosa



j)Orthoconchoecia atlantica



k) Orthoconchoecia haddoni



l)Paraconchoecia cophopyga

Plate.6.2 (j) – (l) Photographs of some of the planktonic ostracods obtained from the Arabian Sea and Bay of Bengal.

Table 6.1 Mean abundance of ostracod species (ind.m^{-3}) during different seasons in the Arabian Sea. '$\overline{X}$' denotes mean abundance, 'σ' denotes standard deviation and 'C.V' denotes Coefficient of variation.

Species (ind.m^{-3})	Spring Inter Monsoon			Summer Monsoon			Fall Inter Monsoon			Winter Monsoon		
	$\overline{X}$		C.V	$\overline{X}$		C V	$\overline{X}$	σ	C V	$\overline{X}$		C.V
Alacia alata (Muller,1894)	1.22	8.79	721	8.60	98.15	1142	65.07	757.03	1163	0.52	2.95	569
Archiconchoecissa cucullata (Brady,1902)	0.01	0.22	1476	0.32	1.77	545	0.35	1.98	562	0.23	1.19	520.78
Bathyconchoecia angeli (George,1977)			0	0.02	0.26	1536	0.01	0.13	1559	0.14	0.94	654.61
Conchoecetta acuminata (Claus,1890)	5.20	17.66	340	27.71	98.18	354	14.89	65.56	440	2.61	13.42	514.18
Conchoecetta giesbrechtii(Muller,1906)	8.51	29.13	342	30.31	82.56	272	30.02	91.91	306	11.24	35.23	313.48
Conchoecia macrocheira (Muller,1906)	0.65	6.54	1008	1.17	8.32	714	5.43	35.49	654	0.64	3.53	549.36
Conchoecia magna (Claus,1874)	3.57	15.49	434	7.85	28.78	366	21.22	81.09	382	6.47	18.41	284.67
Conchoecia parvidentata (Muller,1906)	0.37	2.05	560	0.41	2.35	580	0.83	4.10	492	2.49	8.01	322.51
Conchoecia subarcuata (Claus,1890)	76	1113	1472	197	3015	1532	1	8	542	0.35	3.00	849.61
Conchoecilla chuni (Muller,1906)			0	0.01	0.10	1536	0.04	0.46	1045	0.02	0.21	1151.29
Conchoecilla daphnoides (Claus,1874)	1.10	7.45	677	0.99	5.30	536	0.89	5.36	606	0.08	0.71	839.36
Conchoecissa imbricata (Brady,1880)	2.33	12.66	544	0.20	1.64	824	0.14	1.27	936	0.01	0.11	1202.31
Conchoecissa plinthina (Muller,1906)	0.05	0.58	1170			0	0.02	0.36	1559			
Conchoecissa symmetrica (Muller,1906)	0.07	0.78	1059	0.28	1.64	582	0.23	2.56	1123	0.05	0.59	1253.25
Cypridina dentata (Muller,1906)	768	3408	444	2558	11016	431	2292	7542	329	1175	5928	552
Discoconchoecia discophora (Muller,1906)	0.05	0.45	936	1.28	10.54	821	0.11	0.89	846	0.17	1.90	1098.63
Discoconchoecia elegans(Muller,1906)	3.21	9.32	290	1.33	5.36	403	1.12	7.76	693	0.36	3.03	850.50
Euchonchoecia chierchiae (Muller,1890)	0.72	6.76	937	6.56	61.91	943	5.06	24.83	491	0.77	6.44	839.34
Euconchoecia aculeata (Scott,1894)	377	1410	374	972	3613	372	144	997	693	82.89	447.07	539.36
Felia bicornis (Muller,1906)	0.12	0.94	805	0.17	1.07	639	0.19	2.36	1225	0.26	2.16	840.39
Halocypria globosa (Claus,1874)	0.15	1.77	1158	0.21	1.29	624	0.76	7.89	1036	0.40	3.33	841.52
Halocypris brevirostris (Dana,)			0	0.21	2.51	1208	9.52	148.44	1559			
Halocypris inflata (Dana,1849)	0.13	1.02	773	0.10	0.74	715	0.07	0.59	832	0.27	2.21	814.20
Macroconchoecia caudata (Muller,1906)			0	0.15	0.91	614	0.04	0.40	892	0.04	0.35	819.89
Macroconchoecia reticulata (Muller,1906)	0.01	0.16	1476	0.08	0.69	833	0.07	0.92	1236	0.14	1.65	1218.97
Metaconchoecia krytophora	4.40	17.60	400	11.58	103.71	895	4.13	29.32	710	0.86	5.59	649.09
Metaconchoecia obtusa (Goodday,1981)	0.05	0.76	1476	0.45	3.15	693	1.18	14.17	1197	0.34	3.90	1132.50
Metaconchoecia rotundata (Muller,1890)	7.94	23.92	301	17.55	76.31	435	32.55	88.28	271	21.65	69.11	319.21

Mikroconchoecia acuticosta (Muller,1906)	0.01	0.12	1098	0.17	1.66	976	0.81	6.14	759	0.28	3.97	1431.40
Mikroconchoecia curta (Lubbock,1860)	3.25	11.25	346	3.93	18.94	482	5.13	23.04	449	5.63	18.78	333.69
Mikroconchoecia echinulata (Claus,1891)	0.10	0.81	795	0.04	0.67	1536	0.37	2.26	612			
Mikroconchoecia stigmatica (Muller,1906)			0	0.04	0.35	926	0.05	0.45	992	0.27	2.70	1002.77
Orthoconchoecia atlantica (Lubbock,1856)	7 73	41.53	537	82.27	370.18	450	8.71	31.89	366	2.23	8.41	376.72
Orthoconchoecia bispinosa (Claus,1890)	0.79	3.72	473	4.78	29.28	613	1.00	4.54	456	0.99	8.26	837.28
Orthoconchoecia haddoni (Brady &Norman,1896)	0.24	2.19	904	7.42	72.89	982	2.90	14.39	497	1.76	12.46	707.67
Orthoconchoecia striola (Muller,1906)	0.29	1.96	673	0.65	4.35	672	3.59	30.34	846			
Paraconchoecia cophopyga (Muller,1906)			0	0.11	0.71	644	0.02	0.26	1559	0.05	0.76	1615.55
Paraconchoecia dasyophthalma (Muller,1906)	0.02	0.27	1476	0.18	1.80	1028	0.06	0.64	1105	0.04	0.46	1196.36
Paraconchoecia decipiens (Muller,1906)	0.13	0.92	717	2.56	12.44	485	1.34	6.97	522	0.75	7.20	959.90
Paraconchoecia dorsotubercrdata (Muller,1906)	0.08	0.78	939	0.32	2.39	746			0	0.03	0.41	1615.55
Paraconchoecia inermis (Claus,1890)	2.31	10.69	464	2.98	9.76	327	5.24	21.15	404	1.04	6.14	588.10
Paraconchoecia mamillata (Muller,1906)			0			0	0.11	1.34	1169			
Paraconchoecia oblonga (Claus,1890)	0.24	2.68	1096	0.27	2.19	822	6.82	30.82	452	0.31	2.36	760.45
Paraconchoecia spinifera (Claus,1891)	0.20	1.82	929	4.09	31.14	761	0.86	4.32	505	1.10	14.25	1295.53
Platyconchoecia prosadene (Muller,1906)	0.01	0.14	1476	0.19	1.67	875	0.10	1.10	1134	0.15	1 18	769.79
Porroecia parthenoda (Muller,1906)	0.30	2.78	936	0.10	0.83	805	0.70	3.97	568	0.40	2.91	731.15
Porroecia porrecta (Claus,1890)	0.16	1 15	702	0.22	1.24	557	0.12	1.16	973	0.13	1 14	886.13
Porroecia spinirostris (Claus,1874)	0.02	0.24	1098	0.10	1.48	1485	1.16	7.28	627	0.57	4.87	857.77
Proceroecia macroprocera (Angel,1971)	0.08	0.91	1098	0.38	2.45	652	0.26	1.99	776	8.34	134.11	1607.22
Proceroecia procera (Muller,1894)	2.95	8.82	299	10.66	50.34	472	7.96	26.49	333	8.22	25.04	304.48
Pseudoconchoecia concentrica (Muller,1906)	0.15	1.91	1236			0	0.19	2.10	1077			
Total ostracods	1279.53			3966.16			2678.52			1340.27		

Table 6.2 Mean abundance of ostracod species (ind.m^{-3}) in the different depth layers during different seasons in the Arabian Sea.

	Mean abundance (ind.m^{-3})																			
	Spring Inter Monsoon					Summer Monsoon					Fall Inter Monsoon					Winter Monsoon				
	MLD	BT-TT	300-BT	500-300	1000-500	MLD	BT-TT	300-BT	500-300	1000-500	MLD	BT-TT	300-BT	500-300	1000-500	MLD	BT-TT	300-BT	500-300	1000-500
A. alata	2.86	2.06	0.20	0.0	0.06	25.06	1.61	5.03	0.87		232.91	3.00	11.03	0.57		0.08	0.74	1 70	0.04	0.05
*A. cucullata**				0.0	0.08				1.23	0.78		0.02		1.21	0.60		0.34		0.37	0.56
B.angeli				0.0					0.10					0.04			0.13	0.30	0.20	0.12
C.acuminata	9.07	5.10	10.25	0.53	0.27	47.77	20.05	46.31	0.72	0.09	38.00	11.52	10.35	0.22	0.03	0.77	9.13	2.83	0.83	
C. chuni										0.04				0.22	0.02			0.05	0.04	
*C. daphnoides **		3.42		0.41	0.92	0.31			3.18	2.41	1.07	0.06	0.49	0.87	1.74				0.29	0.18
C. dentata	2325	921	13	0	0	7090	1306	81	0	0	6301	2291	166	3	11	3107	1334	89	12	2
C. giesbrechtii	18.03	4.75	13.44	3.63	1.81	27.15	29.33	69.09	4.87	6.41	55.22	39.91	26.27	2.61	1.02	7.21	32.43	15.73	1 18	0.04
C. magna	4.05	1.22	8.58	2.86	2.32	5.80	3.96	21.30	4.00	3.66	52.61	11.85	17.85	2.48	3.17	4.58	11 18	11.32	4.94	0.05
C. parvidentata				1.18	0.90				1.23	1.30			0.14	0.65	3.54	0.73	2.14	2.47	6.17	1.45
*C. plinthina**		0.15		0.07											0.12					
C. subarcuata	328.57	0.19	1.11			694.24	0.28	0.88	1.23	0.52	2.11	0.64	3.99	0.07	0.12	0.13	1.63			0.12
D. discophora			0.17	0.05	0.06	2.12	1.22	1.65	0.21	0.04			0.28	0.27	0.03		0.25	0.55	0.08	
D. elegans	1.06	1.26	5.18	7.10	3.10		0.19	0.66	3.28	3.95	0.42	0.28	2.90	1.75	0.54		1.06	0.75	0.04	
E. aculeata	903	659	23	0	0	2451	925	97	1	0	454	50	51	0	5	217	79	45	18	1
E. chierchiae	1.95	0.39	0.98	0.05	0.04	21.07	0.86	1.39	0.67		12.43	2.69	4.37	0.52	1.04	0.21	0.11	2.40	0.78	0.36
*F. bicornis**			0.49	0.13	0.08	0.15	0.22	0.06	0.15	0.17	0.56		0.08	0.09	0.07	0.51	0.11	0.52		
H. brevirostris						0.57	0.08		0.10	0.04		37.93								
H. globosa	0.52			0.16	0.04	0.18	0.04		0.36	0.54	2.25	0.61			0.03	0.74	0.70	0.38		
H. inflata			0.33	0.21	0.23		0.07		0.21	0.32		0.02	0.15	0.13	0.07	1.06				
*M. acuticosta**					0.06		0.07	0.83			0.42	2.09	0.99				1.33		0.12	0.05
*M. caudata**									0.82	0.09		0.13		0.05	0.02			0.08	0.09	0.05
M. curta		4.27	5.45	3.21	4.00	4.42	2.79	8.44	1.85	0.35	11.56	3.26	4.62	1.39	0.81	2.18	7.86	14.48	2.49	1.27
*M. echinulata **			0.19		0.39			0.24			0.09	0.88	0.60	0.09	0.02					
M. krytophora	3.55	5.11	9.18	4.05	0.39	27.85	3.58	6.77	5.23	3.88	12.87	1.80	0.99		0.34		1.49	0.83	1.35	0.98
*C. macrocheira**	0.48		2.54		0.66		4.06			0.11	8.93	3.85	10.69	0.13	1.04		1 18	1.31	0.29	0.63
M. obtusa					0.29			1.35	1.08	0.20	3.36	0.21	0.68	0.61			0.62	1.13		
*M. reticulata**					0.06				0.26	0.26				0.34	0.05		0.65		0.08	

M. rotundata	8.62	7.56	16.85	5.42	1.85	13.25	11.67	53.10	3.08	2.32	44.38	31.67	51.90	12.30	7.39	5.81	42.46	50.01	10.56	1.25
M. stigmatica*										0.24		0.06	0.14		0.03	0.31		0.71	0.16	0.09
O. atlantica	19.96	8.82	5.37	0.16	0.10	200.49	61.30	42.87	2.51	0.43	12.22	14.29	10.17	0.35	0.14	1.99	4.73	3.42	0.82	0.02
O. bispinosa		0.12	3.85	0.60	0.10	8.99	2.89	6.98	0.82	0.11	2.17	0.84	0.79	0.26	0.10	0.45	2.83	1.11	0.55	0.13
O. haddoni			1.47			18.43	4.58	3.78	1.23	0.15	4.36	3.62	4.76			4.00	1.44	1.90	0.45	
O. striola			1.33	0.14	0.27	0.85	0.22		1.03	1.12	11.26	1.33	0.70	0.39	0.24					
P. concentrica	0.55		0.17									0.47			0.39					
P. cophopyga*								0.34	0.21	0.09				0.09		0.18				
P.dasyophthalma*				0.11					0.82	0.26	0.12				0.14		0.07	0.13		
P. decipiens					0.72		1.84	5.79	2.92	3.27	0.57	0.56	2.95	2.70	0.12		3.52	0.32	0.20	
P.dorsotuberculata*				0.37	0.10		0.40	0.77	0.15	0.28						0.10				
C. imbricata*	3.33			3.88	4.96	0.28		0.47	0.10	0.11	0.26			0.30	0.05					0.05
P. inermis	3.85	0.89	3.23	3.12	0.68		0.60	8.89	4.00	3.46	1.08	8.56	12.33	2.64	0.89	0.90	0.25	2.04	1.88	
P. macroprocera				0.32	0.15				1.49	0.84			0.44	0.57	0.37	32.34				0.25
P. mamillata*												0.32	0.15		0.03					
P.oblonga	0.71			0.47		0.68	0.09	0.13	0.10	0.04	8.11	10.43	10.59	1.09		0.63	0.55		0.21	0.05
P. parthenoda	0.73			0.47	0.27				0.36	0.28		0.04	2.88	0.70	0.31		1.23	0.09	0.50	0.35
P.porrecta				0.46	0.47				0.87	0.51		0.12		0.35	0.12	0.21	0.14		0.25	0.02
P. procera	2.21	1.58	8.04	2.84	1.25	13.89	7.56	20.41	4.15	1.32	4.36	2.32	20.86	11.59	2.14	1.44	10.82	17.64	10.57	1.76
P. prosadene				0.05		0.53			0.15	0.11		0.26			0.17				0.73	0.09
P. spinifera			0.81	0.13	0.23	4.11	1.93	11.89	0.36	1.08	1.40	0.43	1.70	0.30	0.12	3.57	0.81	0.18		
P. spinirostris					0.12			0.53		0.02	3.89	0.24		0.13	0.18		2.49	0.54		
C. symmetrica	0.22	---	0.10		0.04	0.29	0.14	0.27		0.71	0.51			0.48		0.13	0.07			
mean abund	3638	1627	135	42	27	10660	2393	499	57	42	7285	2536	434	52	44	3394	1557	269	77	13

Table. 6.3 Ostracod species distribution (ind.m^{-3}) in the coastal and oceanic region of the mixed layer of the Arabian Sea during different seasons.

Species (ind.m^{-3})		**Spring Inter monsoon**		**Summer monsoon**		**Fall inter monsoon**		**Winter monsoon**	
		MLD							
		Coastal	Open	Coastal	Open	Coastal	Open	Coastal	Open
1	***A. alata***		6.67	4.14	2.40	58.17	642.80	---	---
2	***A. cucullata***	---	---			---	---	---	---
3	***B. angeli***	---	---	---	---	---	---	---	---
4	***C.acuminata***	---	4.92	95.07	18.01	36.83	20.40	0.23	---
5	***C. daphnoides***	---	---	---	0.96	2.60	0.58	---	---
6	***C.dentata***	660	3444	6165	7466	5485	3616	2838	10671
7	***C. giesbrechtii.***	4.50	9.94	37.18	5.75	47.51	47.08	17.59	2.56
8	***C. magna***	---	4.69	5.76	6.69	33.58	91.12	8.95	2.54
9	***C.parvidentata***	---	---	---	---	---	---	0.48	0.44
10	***C.plinthina***	---	---	---	---	---	---	---	---
11	***C. subarcuata***	---	---	---	---	3.15	3.23	---	---
12	***D. discophora***	---	---	---	---	---	---	---	---
13	***D.elegans***	---	---	---	---	---	1.31	---	---
14	***E. aculeata***	286	1307	1817	3054	172	130	379	57
15	***E. chierchiae***	---	---	35.54	4.99	17.79	9.37	---	0.68
16	***F. bicornis.***	---	---	---	---	1.65	---	---	---
17	***H.brevirostris***	---	---	1.66	---	---	---	---	---
18	***H. globosa.***	---	---	---	---	0.96	0.28	1.96	---
19	***H. inflata***	---	---	---	---	---	---	0.30	---
20	***M. acuticosta.***	---	---	---	---	---	1.31	---	---
21	***M.caudata***	---	---	---	---	---	---	---	---
22	***M. curta.***	---	---	10.59	2.40	22.97	6.55	1.12	5.60
23	***M. echinulata***	---	---	---	---	---	0.28	---	---
24	***M. krytophora***	---	6.22	68.81	11.48	14.05	5.97	---	---
25	***C.macrocheira***	---	---	---	---	0.65	2.62	---	---
28	***M. obtusa***	11.28	---	29.83	3.35	41.99	19.51	8.94	1.66

29	***M. stigmatica***	---	---	---	---	---	---	0.94	---
30	***O. atlantica***	37.54	---	363.87	1.91	25.52	11.10	2.42	0.49
31	***O. bispinosa***	---	---	21.95	---	3.54	3.01	---	0.61
32	***O. haddoni***	---	---	48.16	---	8.54	---	11.62	0.61
33	***O. striola***	---	---	2.48	---	29.48	---	---	---
34	***P. concentrica***	---	---	---	---	---	---	---	---
35	***P. cophopyga***	---			---	---	---	---	0.61
36	***P.dasyophthalma***		---	---	---	---		---	---
37	***P. decipiens***	---	---	---	---	---	---		---
38	***P.dorsotuberculata***	---	---	---	---	---	---	---	---
39	***C. imbricata***	---	---	0.83	---	0.76	---	---	---
40	***P. inermis***	---	1.78	---	---	3.18	---	2.75	---
41	***P. macroprocera***	---	---	---	---	---	---	98.48	---
42	***P.mamillata***	---	---	---	---	---	---	---	---
43	***P. oblonga***	---	---	---	---	23.97	---	---	0.66
44	***P. parthenoda***	---	---	---	---	---	---	---	---
45	***P. porrecta***	---	---	---	---	---	---	0.63	---
46	***P. procera***	---	0.89	37.32	1.07	1.52	2.87	1.21	1.70
47	***P. prosadene***	---	---	0.62	0.96	---	---	---	---
48	***P. spinifera***	---	---	10.37	---	3.32	0.85	10.86	---
49	***P.spinirostris***	---	---	---	---	---	12.04	---	---
50	***C. symmetrica***	---	0.72	---	---	1.52	---	---	---

Table. 6.4 Mean abundance of ostracod species (ind.m^{-3}) during day and night in the mixed layer and thermocline of the coastal stations of the Arabian Sea during spring intermonsoon and summer monsoon.

	Inter Monsoon Spring				**Summer Monsoon**			
	Mixed Layer		**Thermocline**		**Mixed Layer**		**Thermocline**	
Species (ind.m^{-3})	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
A.alata						7.94	0.20	6.69
C.acuminata			1.75		43.12	130.16	22.59	20.47
C.dentata	978	288	575	2614	2755	11614	1041	779
C.giesbrechtii	2.29	7.08			7.31	67.56	28.09	21.95
C.magna				3.42	0.60	10.14	2.60	5.19
E.aculeata	259	317	230	2189	1102	3386	376	478
E.cherchii					6.10	68.12	0.31	4.71
M.Curta			9.59	15.00		20.29	0.47	3.76
M.rotundata	20.95		12.98	13.87	12.05	45.24	8.99	2.38
O.atlantica	69.71			1.24	107.54	536.10	122.41	110.94
O.bispinosa					3.89	36.23	1.71	3.92
O.haddoni						92.31	5.96	3.57
P.procera			1.04	1.80	13.58	51.15	18.11	13.52
P.spinifera					1.27	17.96	4.99	3.12

Table. 6.5 Mean abundance of ostracod species (ind.m^{-3}) during day and night in the mixed layer and thermocline of the coastal stations of the Arabian Sea during fall intermonsoon and winter monsoon.

	Fall intermonsoon				**Winter monsoon**			
	Mixed Layer		**Thermocline**		**Mixed Layer**		**Thermocline**	
Species (ind.m^{-3})	Day	Night	Day	Night	Day	Night	Day	Night
A.alata	3.33	40.61	0.34	1.56				
C.acuminata	44.95	38.74	12.93	9.95		0.39	24.36	3.97
C.dentata	6	3872	132	594	1163	3997	248	6342
C.giesbrechtii	72.34	34.28	43.08	40.25	0.77	29.24	56.27	19.24
C.magna	39.37	42.72	28.40	26.26	4.70	11.90	10.04	7.70
E.aculeata	55	166	16	79	85	583	246	73
E.cherchii	20.37	23.11		4.56				
M.Curta	3.33	22.22	3.49	8.31	2.74		26.11	2.86
M.rotundata	58.89	8.89	14.20	21.11	2.30	13.54	137.51	23.46
O.atlantica	44.07	9.26		24.79		4.10	5.70	6.38
O.bispinosa	4.94	3.70	0.22	3.11				0.55
O.haddoni		14.81	1.31		0.63	19.22		4.10
P.procera		3.70		2.34		2.05	8.22	17.14
P.spinifera	8.11		1.31		1.37	17.44		

Table.6.6 Mean abundance of ostracod species (ind.m^{-3}) during day and night in the different depth layers of the oceanic stations of the Arabian Sea during spring intermonsoon.

Season	**Inter Monsoon Spring**									
Depth (m)	**Mixed Layer**		**Thermocline**		**300-bt**		**500-300**		**1000-500**	
D/N	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
A.alata	12.50		6.62	6.72				---	0.11	
C.acuminata	4.08	6.86	0.46	3.28	13.02	9.88	0.86	1.25	0.46	0.65
C.daphnoides								0.75	1.37	
C.dentata	1155.80	7069.52	732.09	778.23	32.54	9.68				
C.giesbrechtii	7.40	14.99	2.99	2.35	16.45	13.03		0.50	0.91	2.40
C.magna	2.04	9.01	0.83	2.99	6.90	7.23	4.10	1.25	1.14	4.15
D.elegans				1.22	8.89	2.79	2.29	1.99	0.34	0.58
E.aculeata	318.83	2842.95	138.24	494.72	9.18	11.26				0.15
M.Curta			0.37	0.29		3.15	2.00	3.50	3.31	6.76
M.kryptophora		15.56	11.99			1.71	1.71	2.75	0.46	0.15
M.rotudata			0.74	1.80	13.66	12.51	1.43	3.50	0.46	2.18
O.atlantica			0.74	3.58					0.34	0.15
P.procera		2.22	1.92	3.61	3.23	0.70	6.29	0.75	0.23	1.89

Table. 6.7 Mean abundance of ostracod species (ind.m^{-3}) during day and night in the different depth layers of the oceanic stations of the Arabian Sea during summer monsoon.

Season	Summer Monsoon									
Depth (m)	Mixed Layer		Thermocline		300-bt		500-300		1000-500	
D/N										
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
A.alata		3.77		0.94			1.14	0.62		
C.acuminata	21.63	17.48	13.92	14.27	30.56	18.09				
C.chuni					---					
C.daphnoides		1.50		---				2.31	1.60	2.09
C.dentata	6736.97	8364.01		2215.13	40.18	67.35		---	---	---
C.giesbrechtii	12.44	2.82		10.86	89.69	53.10	2.57	3.08	2.80	14.00
C.magna		10.51			2.85	1.06	2.29	2.00		2.52
D.elegans			6.33	---			2.00	2.00		8.48
E.aculeata	2669.55	3465.02	173.42	889.93	266.71	51.26				
M.Curta	---	3.77		0.39	8.57	7.23	1.43	1.38		
M.kryptophora	19.55	8.27		6.98	14.25	9.49	9.14	8.15		2.58
M.rotudata	10.53			1.18	15.14	19.55	7.14			
O.atlantica		3.01		0.72	1.72	2.99				
P.procera		1.68		0.99	0.89	3.42	3.71	3.54	0.80	0.25

Table. 6.8 Mean abundance of ostracod species during day and night in the different depth layers of the Oceanic stations of the Arabian Sea during Fall inter monsoon

Season	**Fall intermonsoon**									
Depth (m)	**Mixed Layer**		**Thermocline**		**300-bt**		**500-300**		**1000-500**	
D/N	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
A.alata	1.98	4.65		0.45	---					
C.acuminata	32.49	13.96	32.15	3.75	21.31	0.95	---		---	
C.chuni	---			---				0.67		
C.daphnoides		---	0.42				0.44	0.67	0.40	0.10
C.dentata	644.77	5345.93	2240.58	1990.64	501.00	199.92	2.44	2.67	7.50	10.50
C.giesbrechtii	80.72	23.27	60.76	11.94	6.96	17.05	2.22			0.30
C.magna	100.41	125.48	4.69	22.49	60.64	12.50	1.78	2.67	0.90	0.30
D.elegans	0.99	2.33		0.22	---	2.65		4.40	0.10	1.40
E.aculeata	90.06	191.73	65.62	23.24	20.13	24.92		1.33	13.70	9.20
M.Curta	4.94	11.63	2.61	1.12	---		0.89	1.00		1.30
M.kryptophora	13.93			---						0.20
M.rotudata	29.80	11.63	66.68	16.94	46.95	51.96	10.22	16.33	11.90	13.00
O.atlantica	15.55	11.63	29.78	3.87		---				0.50
P.procera	2.78	4.41	0.33	13.83	---	28.27	2.44	17.20	2.00	5.00

Table.6.9 Mean abundance of ostracod species (ind.m^{-3}) during day and night in the different depth layers of the oceanic stations of the Arabian Sea during winter monsoon

Season	**Winter monsoon**									
Depth (m)	**Mixed Layer**		**Thermocline**		**300-bt**		**500-300**		**1000-500**	
D/N	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
A.alata			1.29	1.09		2.37				
C.acuminata			0.68	9.41		1.60	2.00			
C.chuni								0.21		
C.daphnoides		11897.21					0.89		0.36	
C.dentata	6137.00	5.18	16.39	188.11	21.19	32.72	3.33	8.00		1.70
C.giesbrechtii		4.25	12.08	19.98		9.01	1.11	0.40		
C.magna	0.81		4.00	15.34	1.60	3.03		0.40		
D.elegans		106.15	0.64							
E.aculeata	13.13		22.50	57.19	0.78	5.76	0.67	2.60		0.50
M.Curta	10.40		5.79	10.46	2.56	7.43	1.11	0.20	2.04	0.50
M.kryptophora				6.90		2.31			2.40	0.20
M.rotudata	2.42		2.90	28.59	13.22	14.62	7.33	0.20	1.60	3.30
O.atlantica		1.23	0.76	0.82	0.74	3.91		0.82		0.10
P.procera	3.18		1.90	4.35	20.47		8.22	6.60	1.82	2.40

Table 6.10a3 Way ANOVA for ostracod abundance in the depth layers of the coastal stations of the Arabian Sea, for comparing between seasons, between day and night, between stations in different latitudes.

Source	dof	Coastal stations	
		F ratio	
		MLD	Thermocline
Seasons(A)	3	1.0149 ^{ns}	0.2249 ^{ns}
Day/Night(B)	1	0.4399 ^{ns}	0.0436 ^{ns}
Latitudes(C)	6	0.8267 ^{ns}	0.9639 ^{ns}
AB interaction	3	1.3552 ^{ns}	1.4310 ^{ns}
BC interaction	6	1.6138 ^{ns}	1.1596 ^{ns}
AC interaction	18	1.6631 ^{ns}	1.1529 ^{ns}
Error	18		
Total	55		

Table 6.10b - 3 Way ANOVA for ostracod abundance in the depth layers of the oceanic stations of the Arabian Sea, for comparing between seasons, between day and night, between stations in different latitudes.

Source	dof	Oceanic stations				
		F ratio				
		MLD	thermocline	300-BT	500-300	1000-500
Seasons(A)	3	0.2340	4.473*	4.3076*	1.0423 ^{ns}	3.9784*
Day/Night(B)	1	6.5024*	9.1521*	5.5162*	0.4466 ^{ns}	0.5808 ^{ns}
Latitudes(C)	6	0.5825 ^{ns}	1.3184 ^{ns}	0.7328 ^{ns}	0.9203 ^{ns}	3.3897*
AB interaction	3	1.0384 ^{ns}	2.7541 ^{b}	1.0680 ^{ns}	0.9316 ^{ns}	1.1239 ^{ns}
BC interaction	6	0.4325 ^{ns}	0.6760	0.9447 ^{ns}	1.1359 ^{ns}	1.3127 ^{ns}
AC interaction	18	1.4239 ^{ns}	2.0987 ^{a}	0.7375 ^{ns}	0.9895 ^{ns}	3.3317*
Error	18					
Total	55					

dof degree of freedom, F ratio- F statistic used for the test Calculated F ratio is significant at (*)5% level ($P < 0.05$), (**) at 1% level ($P < 0.01$), (^{a}) at 6%level ($P < 0.07$), (^{b}) at 7% level($P < 0.08$), (^{c}) at 10%level($P < 0.1$), (^{d}) at 11%level ($P < 0.11$),(^{ns}) not significant

Table 6.11 Two way nested ANOVA for comparing seasons based on ostracod species in the MLD and thermocline layer of the coastal stations .

DEPTH	Source	dof	MSS	F ratio	R	C	GH conditions	$F_{S'}$	Remarks
MLD	Among groups(Seasons)	3	9795838.67	1.526*				1.05372	(P>0.05)
	Among subgroups (Species)	56	9323061.24	1.4528*	157.097	1.5246	satisfied		
	Error (within subgroups,Stations)	317	6417139.56						
	Total	376							
BT-TT	Among groups(Seasons)	3	2198003.5	12.0723**				4.017	(P<0.05)
	Among subgroups (Species)	73	546370.03	3.0008**	1446.59	1.4456			
	Within Error subgroups(Stations)	403	182070.31						
	Total	479	250215.8						

Table.6.12 Two way nested ANOVA for comparing seasons based on ostracod species in the MLD and thermo cline layer of the oceanic stations.

DEPTH	Source	df	MSS	F ratio	R	C	GII conditions	$F_{S'}$	Remarks
MLD	Among groups(Seasons)	3	899922666.6	2.66999*	338.131	1.4456	satisfied	0.9113651	(P>0.05)
	Among subgroups (Species)	61	98108233.03	2.91297*					
	Within Error subgroups(Stations)	403	33679761.14						
	Total	467	42456780.0						
BT-TT	Among groups(Seasons)	3	23852293.33	1.53122				0.8275	(P>0.05)
	Among subgroups (Species)	75	28833615.88	1.85099**	2519.41				
	Within Error subgroups(Stations)	454	15577346.61						
	Total	532	17492840						
300-BT	Among groups(Seasons)		3461.5026	3.4560				1.32	(P<0.23)
	Among subgroups (Species)	65	2683.1179	2.6788**	61.5436	1.4791			
	Within Error subgroups(Stations)	374	1001.5908						
	Total	442	1265.57						
300-500	Among groups(Seasons)	3	9.2435	0.3962				0.259	(P>0.05)
	Among subgroups (Species)	77	35.9492	1.54084**	73.0416	1.4256			
	WithinError subgroups(Stations)	431	23.3309						
	Total	511	25.150						
500-1000	Among groups(Seasons)	3	39.8541	2.21899				1.627	(P<0.19)
	Amongsubgroups (Species)	95	24.6358	1.3717*	57.95	1.3761			
	Within Error subgroups(Stations)		17.9605						
	Total								

Table.6.13 Community structure indices for ostracod species in the different depth layers of the coastal regions of the Arabian Sea during various seasons (Stations averaged). **S**- Number of Species, **R**- Margalef's richness Index, **I**- Simpson's Concentration Index, **H$_{(s)}$** Shannon weaver's species diversity index, **E**- Heip's evenness Index, **D**- Pielou's index of species dominance

Seasons	Depth	S	R	I	H(s)	E	D
SIM	MLD	3.500 ± 1.80	0.335 ± 0.315	0.321 ± 0.244	0.889 ± 0.748	0.773±0.554	0.362±0.304
	BT-TT	3.333 ± 1.751	0.292 ± 0.218	0.370 ± 0.336	1.162 ± 1.148	0.765± 0.811	0.387±0.382
SM	MLD	6.571 ± 4.276	0.7666 ±0.360	0.550 0.249	1.561±0.657	1.111±0.631	0.665±0.302
	BT-TT	7.666 ± 5.853	0.962 ±0.635	0.569 ±0.141	1.601 ±0.473	1.013 ±0.673	0.723±0.235
IF	MLD	6.142 ±4.140	0.6723±0.459	0.379± 0.333	1.222± 1.084	0.789 ±0.812	0.303 ±0.336
	BT-TT	6.000± 3.464	0.772±0.457	0.448 ±0.234	1.283 ±0.598	0.9316±0.763	0.589 ±0.261
WM	MLD	3.714 ±3.302	0.442±0.522	0.440± 0.288	1.281 ± 0.914	0.6933±0.701	0.4746±0.338
	BT-TT	10.285 ±6.343	1.526±0.860	0.629±0.148	2.034±0.220	0.904±0.330	0.672 ±0.220

Table.6.14 Community structure indices for ostracod species in the different depth layers of the oceanic regions of the Arabian Sea during various seasons (Stations averaged). **S**- Number of Species, **R**- Margalef's richness Index, **I**- Simpson's Concentration Index, **H**$_{(s)}$ Shannon weaver's species diversity index, **€** - Heip's evenness Index, **D**- Pielou's index of species dominance.

Seasons	Depth	S	R	I	H(s)	€	D
SIM	**MLD**	3.85±2.193	0.086±0.068	0.411±0.185	1.097±0.519	1.027±0.487	0.5451±0.228
	BT-TT	4.285 ±2.751	0.098±0.083	0.41±0.154	1.018±0.447	0.774±0.384	0.517±0.164
	300-BT	4.8±2.167	0.152±0.064	0.699±0.119	1.961±0.557	1.838±0.101	0.726±0.206
	500-300	4.8 +3.033	0.192±0.121	0.707±0.087	2.128±0.413	1.523±0.258	0.815±0.138
	1000-500	6.4±1.949	0.360±0.102	0.755±0.062	2.346±0.298	1.820±0.194	0.870±0.109
SM	**MLD**	4.571±3.101	0.085±0.065	0.298±0.176	0.765±0.396	0.612±0.429	0.565±0.348
	BT-TT	5.000 ±2.236	0.104±0.069	0.376±0.256	1.094±0.769	0.475±0.410	0.472±0.318
	300-BT	7.000 ±2.160	0.196±0.063	0.642±0.119	1.990±0.397	1.205±0.467	0.772±0.135
	500-300	5.833 ±2.401	0.230±0.107	0.628±0.284	1.969±0.892	1.406±0.680	0.766±0.328
	1000-500	9.667±3.724	0.474±0.202	0.789±0.096	2.712±0.539	1.873±0.534	0.8123±0.149
IF	**MLD**	10.428±5.442	0.247±0.144	0.468±0.306	1.615±1.176	0.674±0.611	0.3845±0.358
	BT-TT	9.571±6.051	0.270±0.209	0.400±0.330	1.344±1.084	0.732±0.712	0.448±0.398
	300-BT	6.142±3.387	0.244±0.165	0.678±0.122	2.016±0.560	1.592±0.459	0.585±0.182
	500-300	5.5±4.324	0.195±0.091	0.458±0.340	1.429±1.124	1.089±0.782	0.4698±0.358
	1000-500	8.857±3.976	0.424±0.205	0.640±0.171	2.111±0.669	1.182±0.52	0.6597±0.168
WM	**MLD**	2.857±1.215	0.070±0.069	0.231±0.257	0.620±0.659	0.545±0.663	0.373±0.397
	BT-TT	7.500±4.461	0.240±0.215	0.415±0.402	1.465±1.433	0.905±0.964	0.434±0.382
	300-BT	5.333±2.582	0.203±0.109	0.578±0.209	1.682±0.707	1.317±0.493	0.668±0.282
	500-300	4.714±3.450	0.221±0.188	0.619±0.195	1.937±0.886	1.204±0.663	0.6119±0.321
	1000-500	6.714±2.984	0.481±0.163	.639±0.317	2.288±0.694	1.810±0.455	0.7024±0.200

* * *

Chapter – 7

OSTRACOD DIVERSITY IN THE BAY OF BENGAL

7.1 Introduction

Previous chapter dealt with the seasonal distribution and abundance of planktonic ostracods in the Arabian Sea. Relatively little is known about the planktonic ostracods in the Bay of Bengal. Some studies in this region were date back to IIOE (George, 1979). This chapter focuses on the seasonal and the vertical distribution of planktonic ostracods in the BoB during different seasons and their relation to various hydrographical parameters.

7.2 Hydrography

The seasonal hydrography and physico chemical characteristics of BoB have been described in Chapter 4.

7.3 Seasonal variation of planktonic ostracods in the Bay of Bengal

In all 55 species of ostracods, 54 belonging to the family Halocyprididae and one to Cypridinidae were found in the Bay of Bengal. Of these 18 species were recorded for the first time within the ostracods community of this area (See the species with * in Table 7.1). The average abundance of ostracod during different seasons were, spring inter monsoon (165 ± 9.52 ind.m^{-3}) summer monsoon (2252 ± 204 ind.m^{-3}), and winter monsoon (279 ± 17.35 ind.m^{-3}). The most abundant species in the BoB was *Euconchoecia aculeata* and its abundances varied between seasons and depth strata. This species was found throughout the BoB during almost all the stations.

Spring Intermonsoon

The mean abundance of ostracods in the BoB during this season was 165 ± 9.52 ind.m^{-3} irrespective of depth and area (Fig.7.1a, 7.2a, 7.3a, &7.5a). About 42 species were identified during this season from the upper 1000 m water column (Table 7.1). The dominant species encountered as *E. aculeata* (39%), *Metaconchoecia rotundata* (15%) *Euconchoecia cherchiae* (11.25%) *Conchoecetta acuminata* (6.78%) *paraconchoecia inermis* (4.91%) and *Orthoconchoecia atlantica* (4.31%).The species which encountered more than 1% were *Conchoecetta giesbrechtii, Conchoecia subarcuata, Conchoecia macrocheira, Paraconchoecia mamillata,* and *Proceroecia procera.*

The mean abundance of ostracods in the MLD during this season was 313 ± 23 ind.m^{-3}. In the MLD the most abundant species (Fig.7.7 &7.10) were *E.aculeata* and *E.chierchiae* with a mean abundance of 163 ind.m^{-3} and 56 ind.m^{-3}. Among the other species *M.rotundata* and *C.acuminata* contributed about 7.5 and 4.3% to the total abundance of Ostracods. In the thermocline depth the compositions of the abundant species were almost same as that of MLD, but the variation was only quantitative. At this depth, the most abundant species were *E.aculeata* and *M.rotundata* with an abundance of 39 ind.m^{-3} and 23.45 ind.m^{-3} and a percentage contribution of 29 and18. Towards the deeper depths the total abundance of ostracods decreased from 95 ind.m^{-3} in 300-BT, 34 ind.m^{-3} in 500-300m and 23 ind.m^{-3} in 1000-500m depth (Fig.7.3 - 7.5). In the 300-BT and 500-300 depth the dominant species was *M.rotundata* with a percentage contribution of 35%. The other species contributed to at 300-BT depth were *E.aculeata* and *C.acuminata* and at 500-300 m depth, were *C.acuminata* and *P.inermis* where as at 1000-500 m, it was *P.mamillata.*

Summer monsoon

Compared to other seasons, the total abundance of ostracods were high during this season (Fig.7.1b -7.5b) with an average of 2252 ± 204 ind.m^{-3} and 39 species were identified (Table7.1). The ostracod community was dominated by *E. aculeata* (63%) and *C. dentata* (27.21%).The other species were *M.rotundata* (1.61%), *P.inermis* (1.02%) and *O.atlantica* (0.58%). Only during this season *C. dentata* was encountered in the southern BoB along 11 and 13°N latitudes (Fig.7.7 & 7.8).

The mean abundance of ostracod in the MLD during the summer monsoon was higher (7107±636 ind.m^{-3}) than other seasons. Both in the MLD and thermocline layer, *E.aculeata* and *C.dentata* contributed to about 58 and 34% and 76 and 7%, respectively to the total abundance. The maximum density of *E. aculeata* was seen during this season at both MLD (4120 ind.m^{-3}) and Thermocline (1125 ind.m^{-3}). In the 300-BT depth also *E. aculeata* contributed to about 81% of the total abundance (Fig 7.10). *P.inermis* was consistently present in the 500-300 m depth strata. In the 1000-500 m depth, *M.rotundata* (21%), *C.imbricata* (11%), *P.nanomamillata* (8.44%), *P.parthenoda* (5.04%), *O.haddoni* and *P.dasyophthalma* (4.22%) formed a relatively good percentage.

Winter monsoon

The mean abundance of ostracods in the MLD was about 724 ± 45 ind.m^{-3} and 45% was contributed by *E.aculeata* and 11% was by *M.rotundata* (Fig.7.1c, 7.2c, 7.3c, 7.4c and 7.5c). The other species that contributed fairly in good number were *C.giesbrechtii, C.magna* and *M.curta.* In the thermocline layer also the most abundant species were *E.aculeata* and *M.rotundata,* comprising about 36 and 12% of the total ostracods. The increasing order of dominance of major species in the 300-BT layer were *M.rotundata* , *C.giesbrechtii,* , *E.aculeata, P.Spinirostris, C.acuminata* and *O.atlantica*, whereas *M. rotundata* (15%) and *Discoconchoecia elegans* (10.3%), were found at 500-300 m and *P.parthenoda* and *P.mamillata* were more common at 1000-500 m water column (Fig.7.10).

7.4 Coastal and Oceanic variation of planktonic ostracods

The maximum abundance of ostracods in the MLD of the coastal regions of BoB was observed during the summer monsoon (6629 ± 808 ind.m^{-3}). The second maximum was seen during winter monsoon (590 ± 24ind.m^{-3}) followed by fall inter monsoon (476 ± 39ind.m^{-3}). During summer monsoon the MLD and the thermocline comprised mainly of *E.aculeata* with an abundance of 5996 ind.$m^{-3}$and 195 ind.m^{-3}, respectively (Fig.7.7), while the abundance decreased to 289 ind.m^{-3} during spring intermonsoon and 148 ind.m^{-3} during winter monsoon. *C.dentata* was present only during summer monsoon at some of the southern stations (Fig.7.8) in low numbers (avg. 105 ind.m^{-3}) compared to the oceanic stations (avg. 3924 ind.m^{-3}). *E.chierchiae* was also present (338 ind.m^{-3}) in the MLD of the coastal regions of the BOB (Table 7.2). Their maximum abundance was seen during summer monsoon. *C.giesbrechtii* and *M.stigmatica* were also abundant in the MLD of the coastal regions during summer monsoon but in other seasons they were present only in very small numbers. Considering the species composition between the coastal and oceanic MLD during intermonsoon spring, the variation between the species composition was less. The other common species in the coastal and oceanic MLD were *C.acuminata, C.macrocheira, M.rotundata, C.magna* whereas at the oceanic MLD *O.atlantica* and *P.inermis* were also present (Table 7.2). *Alacia alata* and *A.cucullata* were present only in the coastal thermocline during winter monsoon, while they were completely absent in the oceanic thermocline.

The total abundance of ostracods in the MLD of the oceanic stations was the highest during summer monsoon with an average of 8445 ind.m^{-3}. *C.dentata* was the most abundant in MLD of the southern oceanic stations with a density of 3924 ind.m^{-3}. Marked seasonality was shown by this species in the BoB. *P.mamillata and P. macroprocera* were totally absent (Table 7.2). in the open ocean regions but they are present in the coastal regions during summer monsoon and winter monsoon.

7.5 Diel vertical migration of Ostracods

The higher densities of ostracods in the MLD during night clearly indicated that there was a significant diel vertical migration. The night densities of ostracods were high at the mixed layer during summer monsoon (Fig 7.6a). Comparison with the abundance plots of day night clearly confirm the DVM of ostracods varying between seasons and depths (Fig 7.6a &b) both in coastal and oceanic regions. The coastal stations showed the highest night densities in the MLD with the migrant density of 14036 ind.m^{-3} while it was less in oceanic stations with 11407 ind.m^{-3} during summer monsoon.

In the coastal stations, *C.dentata* and *E.aculeata* showed DVM during all the seasons. But their maximum densities in the MLD at night were during summer monsoon with an average of 11614 ind.m^{-3} and 3386 ind.m^{-3} respectively. *C.acuminata, C.giesbrechtii, C.magna, E.cherchiae, M.rotundata,O.atlantica, O.haddoni* and *P.procera* also showed high night time abundance during summermonsoon in the MLD of coastal regions (Table 7.3). But the diel vertical migration was not significant.

In the oceanic region, the mean densities of *C.dentata* at night was higher during summer monsoon (7848 ind.m^{-3}) in the MLD (Table.7.5). Night abundance of *E.aculeata* was higher during summer (6996 ind.m^{-3}) followed by winter monsoon (547 ind.m^{-3}) in the oceanic regions (Table.7.5&7.6). *E.aculeata* performed higher vertical migration in the coastal stations during summer monsoon (Table.7.3). *C.magna* and C. *giesbrechtii* showed high night densities only during winter (Table.7.6). Night abundance of most of the species were high during winter monsoon (Table.7.6).

7.6 Statistical analysis

7.6.1 Community structure indices

In the mixed layer of coastal stations, species richness and species diversity was highest during winter monsoon with an average of (0.766±0.235) and (1.7726± 0.7005). In the thermocline layer the species richness (1.658±0.512) and diversity (2.3133± 0.3867) was maximum during spring inter monsoon and least was during winter monsoon (Table.7.9). In the thermocline layer during SIM, a steady decrease in species richness was observed from south (2.0108) to northern latitudes (0.6514).Species diversity also showed a consistent spatial distribution during SIM (CV%= 16.72%). Thermocline depth layers were, richer, more diverse and more evenly distributed than mixed layer depth during SM. During winter compared to different depth strata, MLD is more diverse, but less even, than thermocline. A steady decrease was observed for species richness at deeper layers.

In the mixed layer of the oceanic stations during SIM, the average species richness was 0.6753 with a spatial variation of

49.98%. Comparing with coastal stations, during SIM, open ocean waters were richer, more concentrated, more diverse and more evenly distributed with lower spatial variation for these indices (Table 7.10). Diversity was more homogeneous in the thermocline layer during SIM, with respect to latitude (CV% = 28.25%) with least diversity (1.45) at northern BoB and maximum diversity at 15° N. Thermocline layer was 200% more diverse than MLD during SIM. In the 300-BT layer, species concentration remained almost similar (C.V. % = 19.07%) at all stations with an average of 0.728 during SIM. Maximum diversity was seen in the 300-BT at southern BoB (3.057) than the northern BoB (1.241) during SIM. Species richness and diversity were high in the deeper layers and the highest species richness (2.061±0.829) was at 1000-500m layer during SIM and the diversity (2.4843± 0.5924) was at 1000-500m during winter monsoon (Table 7.10). Comparing with coastal stations it could be inferred that open ocean stations were richer, more concentrated more diverse and then more evenly distributed compared to coastal stations, and only half the heterogeneity over latitudes was observed in the oceanic region during SIM. During winter monsoon, all the depth layers were richer and more diverse in both coastal and oceanic stations (Table 7.10).

7.6.2 Cluster Analysis

Bray Curtis similarity index applied for grouping of ostracod species based on their abundance in the mixed layer during various seasons. The data were computed for species in pairs and species were grouped in to clusters of varied similarity levels. For identifying the groups in different clusters, 40% similarity level was taken and the clusters are depicted as a dendrogram using group linkage clustering technique. The similarity index was computed after transforming the observed species abundance (no.m^{-3}) in to standardized 4th root transformed values. In the case of stations the similarity is presented as a non metric multidimensional scaling diagram.

During spring inter monsoon, 5 different clusters were identified (Fig. 7.11a). Species comprised in Group 1 were *P.spinifera.*, *P.mamillata* and *P.nanomamillata.* The members of this group were generally less abundant.. Group 2 comprised of *H.inflata* and *P.porrecta*. Group 3 consisted of *P.inermis, C.subarcuata, O.bispinosa, E.cherchii and A.alata.* Group 4 composed of the species present in the mixed layer of the coastal regions: *M.curta,C.imbricata,* and *M.macrocheira.* The species included in Group 5 were *C.acuminata, E.aculeata* and *M.rotundata* which were the highly abundant species. Stations grouped based on ostracod abundance given 3 groups of stations (Fig. 7.11b). Group a were comprised of northern stations and characterised with the species, *M.rotundata, C.acuminata, E.aculeata and O.atlantica.* Group b composed of southern coastal stations with *P.inermis, C.giesbrechtii, E.cherchiae* and *E.aculeata* in fairly good numbers. Group c comprised of 3 stations, which were characterised with low abundance of ostracods.

During summer monsoon, the co occurring species, grouped in to 6 clusters (Fig. 7.12a). Group 1 consisted of *F.bicornis,P.parthenoda* and P. *porrecta.*, which were restricted in abundance to < 5 in the mixed layer during this season. Group 2 included *C.subarcuata*, *P. dasyophthalma*, *C.imbricata* and *P.nanomamillata,* displayed very low or even absent in the coastal stations. Group 3 was characterized and included *H.inflata O.atlantica* and *P.oblonga*. and displayed maximum abundance values in the coastal waters. The Group 4 included *H.globosa*, *O.haddoni and P.inermis,* were absent in the oceanic waters during this season. Group 5 were composed of *C.acuminata, C.magna*, and *P. procera* and these species were present in the coastal waters during summer monsoon. Group 6 included species such as *M.rotundata,C.dentata and E.aculeata.* They are the most dominant species during this season. 21 stations sampled during this season, the distribution of stations based on the species abundance showed that 19 stations were grouped in to a single cluster, and two stations 11°N, 80°E and 13°N, 81.8°E distributed separately(Fig. 7.12b). These stations were the southern coastal stations and they were under the grip of upwelling, characterised with high abundance of *E.aculeata.* Cluster a comprised both coastal and oceanic stations from northern and Southern BoB.

During winter monsoon, the ostracod species were grouped into 7 clusters. The observed groups were (Fig. 7.13a) Group 1 of *M.reticulata*, and *O.haddoni*. Group 2 of *C.subarcuata*, *P.macroprocera* . Group 3 of *C.imbricata, P.mamillata, P.Parthenoda.* Group 4 of *H.inflata, M.curta, M.macrocheira and M.rotundata.* Group 5 of *P.spinifera, O.bispinosa, D.elegans and P.decipiens.* Group 6 of *P.procera, A.striata, P.spinifera.* Group 7 of *C.giesbrechtii, E.aculeata, C.acuminata* and *C.magna.* This group is characterised with high abundant species. 20 stations were sampled during winter monsoon, based on the species abundance 3 different clusters were obtained (Fig. 7.13b) at more than 40% similiarity. Cluster a composed of the northern oceanic stations having low abundance of ostracods. Cluster b consisted of the species, *C.acuminata, C.magna*, and *P. procera.* Cluster c composed of stations characterised with high abundance of *M.rotundata,C.dentata and E.aculeata.*

7.6.3 3 way Analysis of Variance (3 way ANOVA)

In the mixed layer of the coastal stations, seasonal differences observed was significant, but only at a lower level of confidence (F

(3, 18) = 2.3489, P < 0.13). But the day and night differences (P>0.05) and latitudinal differences (P>0.05) were all due to sampling variability (Table 7.7a). In the thermocline layer of the coastal stations ostracod abundance varied with respect to seasons, day and night and stations were all due to sampling flctuations (P > 0.05) (Table 7.7b). But in 300-BT stratum in the open ocean stations, significant seasonal differences (F(3,12) = 4.7896, P < 0.05), and latitudinal differences (F(4, 12) = 6.9959, P < 0.01) were observed in ostracod abundance along with high D/N – latitude interaction (F(4, 12) = 4.8946, P < 0.05) and high season – station interaction (F(12,12) = 3.2705, P < 0.05) as indicated by the peak value (Table7.7a &7.7b). In 500-300 depth stratum in open ocean, all the differences: viz. Seasonal, diurnal and latitudinal were not significant (P > 0.05) except for the season – D/N interaction (F (3, 12) = 2.0449, P < 0.16) at a lower level of confidence (at 84%) (Table. 7.7b). In 1000-500 stratum in open ocean, latitudinal difference (F (4, 12) = 2.8270, P < 0.07) and Season-D/N interaction (F (3, 12) = 3.5039, P<0.05) were high (Table 7.7b).

7.6.4 Two way nested Analysis of Variance (2 way nested ANOVA)

Coastal stations

Two way nested ANOVA was applied to MLD in coastal stations. Among species, a significant added variance component was observed ($F_{(39,\ 159)}$ = 2.6730, P < 0.01) which remained almost same in all seasons ($F_{(3,\ 40)}$ = 1.03112, P > 0.05). In the thermocline layer in the coastal stations, among seasons the observed variation was significant at a lower level probability ($F_{(2,\ 46)}$ = 2.1525, P < 0.13) whereas among species, difference observed was highly significant ($F_{(46,\ 198)}$ = 2.9972, P < 0.01) (Table 7.8a). In the 300-BT, 500-300 and 1000-500 depth layers in coastal stations, seasonal differences observed were due to sampling fluctuations ($P > 0.05$). But only in 1000-500 m, among species difference was to be considered as a significant variance component ($F_{(46,\ 182)} = 3.4205$, $P < 0.001$). In lower depth layers species wise differences did not add a significant component to total variance observed (Table 7.8a).

In open ocean stations, all the differences observed in the ostracod species abundance in mixed layer ($F_{(39,\ 177)} = 3.7810$, $P < 0.01$), thermocline layer ($F_{(73,\ 329)} = 3.1248$, $P < 0.001$) and in 300-BT layer ($F_{(44,\ 175)} = 2.3582$, $P < 0.01$) could be attributed to the inherent species wise differences. While in the other three seasons, spring inter monsoon, summer monsoon and winter monsoon the observed differences in the species abundance were found only in the mixed layer depth at a lower level of significance ($F_{(2,\ 38)} = 2.0488$, $P < 0.14$) and in thermocline layer, applying simple test $F_{(21,\ 44)} = 7.8338$, $P < 0.001$). At higher depth zones differences observed could be attributed to sampling fluctuations ($P > 0.05$) (Table 7.8b).

7.7 Discussion

During the study, ostracod community was composed of 55 species. *E. aculeata* was the most dominant species and their abundance varied between seasons and depth strata. George, (1979) also reported similar pattern for this species in the Bay of Bengal. Angel, (1999) observed that halocyprid ostracods are generally more abundant and diverse in waters deeper than 100 m; the maximum abundance of the group is often between 200–400 m and their maximum species richness at 1000 m.

In this study, the sampling was restricted to the upper1000 m, and so the 55 species identified were probably a fraction of the species inhabiting the region. Nevertheless, we observed substantial changes in the abundances, distributions and diversity of ostracods within the study area and between different seasons. A few previous studies have reported the mesozooplankton in the BoB (Nair, et al, 1981, Madupratap et al., 2003), however, studies on the composition and diversity of ostracod during various seasons were scanty. During different seasons, major changes in the hydrographic regime in the region particularly in the northern and Southern Bay of Bengal have been observed. Maximum abundance of ostracods was seen during the summer monsoon. During summer at the surface, cool upwelling waters became restricted to localized upwelling centers and were much reduced close to the coastal regions of southern BoB. The most abundant species in the BoB during SM was *E.aculeata*. During summer in addition to *E. aculeata* , C.dentata were also abundant in the southern BoB. The overwhelming numerical dominance of these two species may be due to the changing hydrographical regime. The presence of *C. dentata* during summer in the southern BoB can be explained through the intrusion of ASHSW in to the BoB (Vinayachandran *et al*, 2002). During Summer monsoon, south westerly winds drags ASHSW to the Southern BoB by forming Summer monsoon current (SMC) at Sri Lanka, and one branch of the SMC moves towards northern BoB through open ocean and the other branch moves through the coastal region up to 15°N. Castillo, (2007) reported that tropical ostracod species has some consistentency with the spread of warm water masses. *C.dentata* abundance is strongly correlated with the salinity, temperature and chlorophyll (Jasmine *et al.,* 2007). The spreading of ASHSW was restricted almost up to the oceanic regions of 15°N and *C.dentata* distribution was restricted only during the summer monsoon up to 15°N. So this species can be considered as an indicator of ASHSW. Highest diversity of ostracods was found in both coastal and oceanic regions in the winter monsoon compared to summer. In the southern zones, and particularly in the coastal areas, *E.aculeata* may flourish, when the upwelling progress, this might be a reason for the reduction in species diversity during summer. In the coastal and open ocean stations , thermocline regions posses more diversity of species than surface layers. *C. giesbrechti* were high abundant, occurred more frequently in the southern and coastal zones during summer (Table. 7.2). During summer monsoon, strong south westerly winds prevailed over the region which was favorable for the upwelling that pushed surface water to offshore and brought cool nutrient rich subsurface water with less dissolved oxygen to surface and thus enriched the biological production (Bhavanarayana *et al.,* 1957; Udayavarma *et al.*, 1959., Madhu *et al.* 2002). *C.giesbrechti* showed a negative correlation with the surface oxygen content was reported by Castillo (2007). Martens (1981) considered *C.giesbrechti* to be an indicator of Equatorial Subsurface Water (ESSW), which is the water mass that underlies the wind-mixed layer (Zuta & Guillen, 1970). Thus, this species may be useful for identifying the upwelling regions. A general reduction of other ostracod species in coastal waters (Table7.2) might be related to the development of the oxygen minimum (OMZ) occurred during upwelling. This low number of ostracod species during upwelling was reflected in the results of species richness and diversity. A few species are adapted to, and favored by oxygen deficiency (Longhurst, 1967; Antezana, 2002), so usually the OMZ has a strong impact on the distributions of the pelagic fauna. Poulsen (1977) concluded that ostracods are poorly adapted to living in waters with oxygen contents less than 2–3 ml/l, so the observed depletion of ostracods during upwelling is not unexpected.

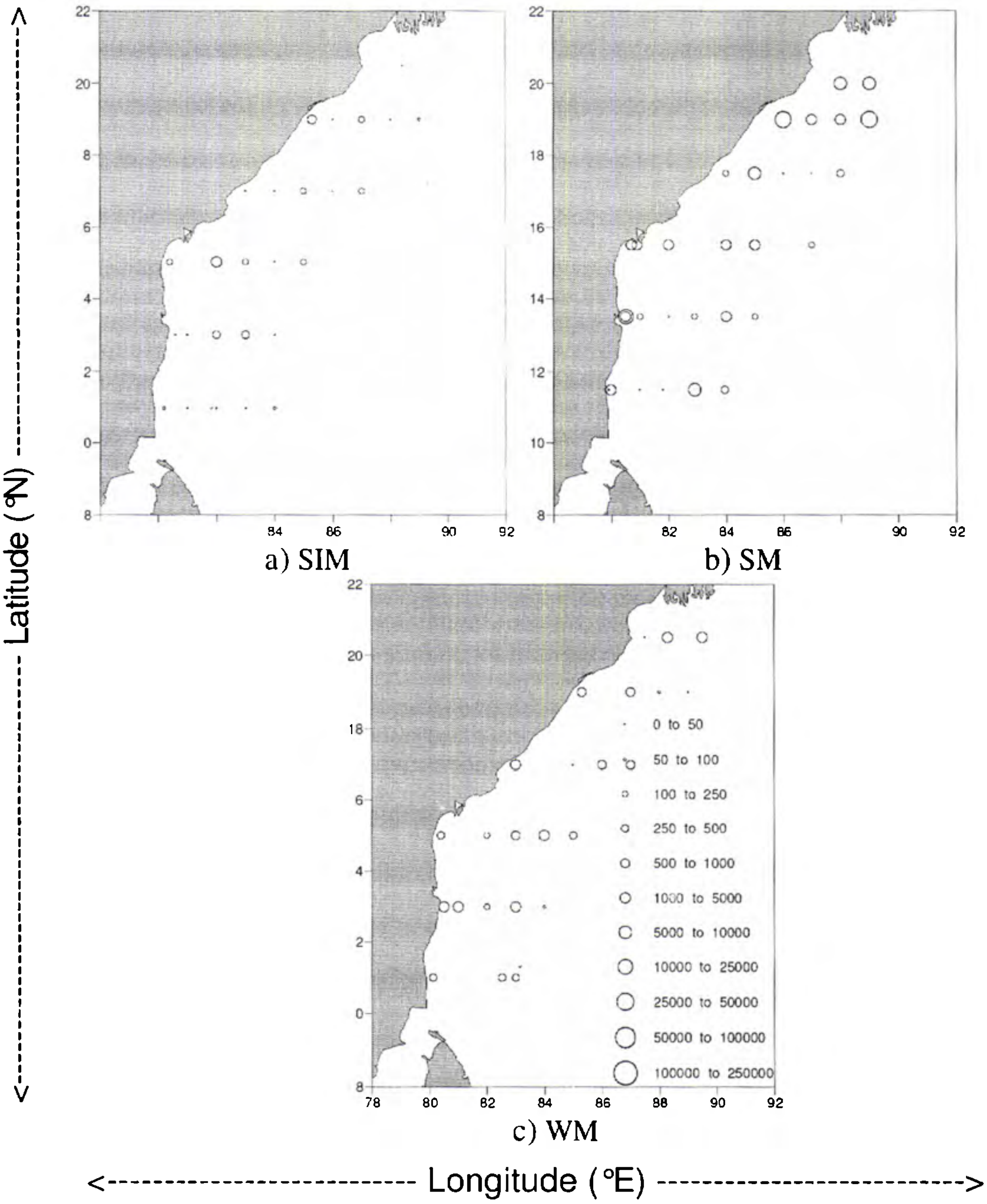
The dominance of *E. aculeata* in the BoB and the presence of *Archiconchoecia striata* only during winter monsoon need to be considered. Both these species are likely to have high intrinsic rates of population growth, but for different reasons. *Archiconchoecia striata* was present only during winter monsoon, in the other seasons this species was entirely absent. The genus *Euconchoecia* is more neritic than other halocyprid genera, and its species have an unusual mode of reproduction (Tseng, 1975, 1976). Like cladocerans, the females brood eggs within the carapace, keeping a consistent number of developing embryos within the brood pouch, each one at a different stage of development. This is because the female lays the eggs one at a time and releases each embryo separately as it reaches maturity. This mode of reproduction probably enables Euconchoecia populations to respond rapidly to environmental improvements in the BoB. *Archiconchoecia striata* has a different strategy whereby it may achieve a high rate of population growth. Adults only have five pairs of claw setae on the caudal furca, compared to the eight pairs that are normal in halocyprids. Newly hatched embryos of halocyprids have just two pairs of caudal furca claws and add an additional pair at each ecdysis. Thus, after the sixth juvenile instar the normal adult has attained its compliment of eight pairs of caudal furcal claws. The implication is that *A. striata* has abbreviated development, attaining maturity neotenously after maybe just three instars (Castillo, 2007). So, this very small species probably has a much shorter life cycle than the other species, enabling it to respond much faster to improving conditions. Sustenance of *A.striata* during winter monsoon was by grazing small picophytoplankton. Under high nitrate condition, large size classes of phytoplankton usually flourish, whereas picoplankton is predominant in nitrate-depleted waters (*Taguchi et al.,* 1992). BoB was highly stratified during winter monsoon and winter cooling did not lead to convective mixing and enrichment of upper layers in the BoB due to intense stratification by the fresh water cap (Banse, 1984; Prasanna Kumar and Prasad, 1996; Madhupratap *et al.,* 1996; Jyothibabu *et al.,* 2004).This may be the reason for reduced chlorophyll *a* and primary production in the BoB. Both *E.aculeata* and *A.striata* are small and so are probably favored by the switch in primary production from being dominated by diatoms under the 'normal' upwelling conditions to being dominated by picoplankton as in stratified conditions (Iriarte & Gonzalez, 2004). Most of the organic material produced is retained within the wind-mixed layer, and there is an increase in gelatinous zooplankton that generates the detrital material on which the ostracods feed (Castillo et al., 2007). This may be the main reason for the sustenance of deep dwelling species beneath the mixed layer during other seasons. During upwelling, sedimentation of large quantities of organic matter resulting from the enhanced high primary production, results in substantial reductions in sub thermocline concentrations in dissolved oxygen. Poulsen (1973) stated that the majority of halocyprid species are intolerant to low oxygen environments and so during upwelling sharp reductions in ostracods populations would be expected as the OMZ intensifies. Conversely, when the upwelling relaxes and the OMZ weakens, the ostracods can re-invade the sub thermocline waters and increasing abundances of diel migrating halocyprids will be encountered in the epipelagic zone at night during summer monsoon, which will tend to be advected on shelf by the circulation. This, combined with cooler SSTs which may be unsuitable for the warm water species, may explain the rather unexpected reductions in ostracod abundances and species richness observed in the present study. *E.aculeata* which sustained throughout the seasons was the result of not only the upwelling but also the ability of this species to generate swarms rapidly, making it very effective in colonizing in the improving environments by reproducing very quickly and being well adapted to feed on the dominated pico- and nanoplankton in the inter monsoon spring. During summer the ostracod community also comprised by *M.rotundata* (1.61%), *P.inermis* (1.02%) *O.atlantica* (0.58%).

O.atlantica, occurred mostly in the coastal regions, during summer monsoon. George, (1978) recorded this species from the west and east coast of India. It is a large heavily-built species and is readily recognizable at all stages. Deevey (1968) reported this species distributed in the upper 500 m throughout the year. *M.rotundata* was found in high abundance in summer monsoon followed by winter and spring Intermonsoon. They were mostly found at a depth of 300-BT. George, (1975) reported that the two species, *C.giesbrechti* and *M.rotundata* were confined to waters below thermocline.

In the Bay of Bengal diel vertical migration of ostracods was less in coastal stations. Somewhat high migration seen in the oceanic stations of the BoB may be due to the less stratification in oceanic region than coastal regions. Ostracod species diversity was high during winter monsoon and low during summer monsoon. Compared to the Arabian Sea and the Bay of Bengal, ostracod diversity was high in BoB than Arabian Sea in both coastal and oceanic stations.

The BoB waters were oligotrophic during most of the year except at the upwelling regions (Madhu et al, 2002) and the areas where episodic events such as eddies occurs (Muraleedharan *et al.*, 2007; Prasanna kumar *et al.*, 2007). However, both phytoplankton standing-crop, as indicated by chlorophyll concentrations, and measures of productivity suggested that the water to the northern

BoB, which was slightly cooler and steeper nutricline, was a little more productive than the water to the southern BoB during winter monsoon. The ostracod standing stock was very clearly associated with the trend in phytoplankton crop and productivity. Connell & Orias (1964) have suggested that at an ecological climax, herbivores are limited by predators rather than by their resources, whereas carnivores are limited by the availability of prey. Yet even carnivores may be distributed to some extent independently of the food resources by forming groupings for activities such as reproduction and mutual protection. Most of the halocyprid ostracods are carnivores and detritivores (Iles, 1961; Castillo, 2007). But the community would not be expected to have an organized structure because of its transient nature.



a) SIM

b) SM

c) WM

Fig.7.1 Spatial distribution of ostracod abundance in the mixed Layer of the Bay of Bengal during different seasons a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

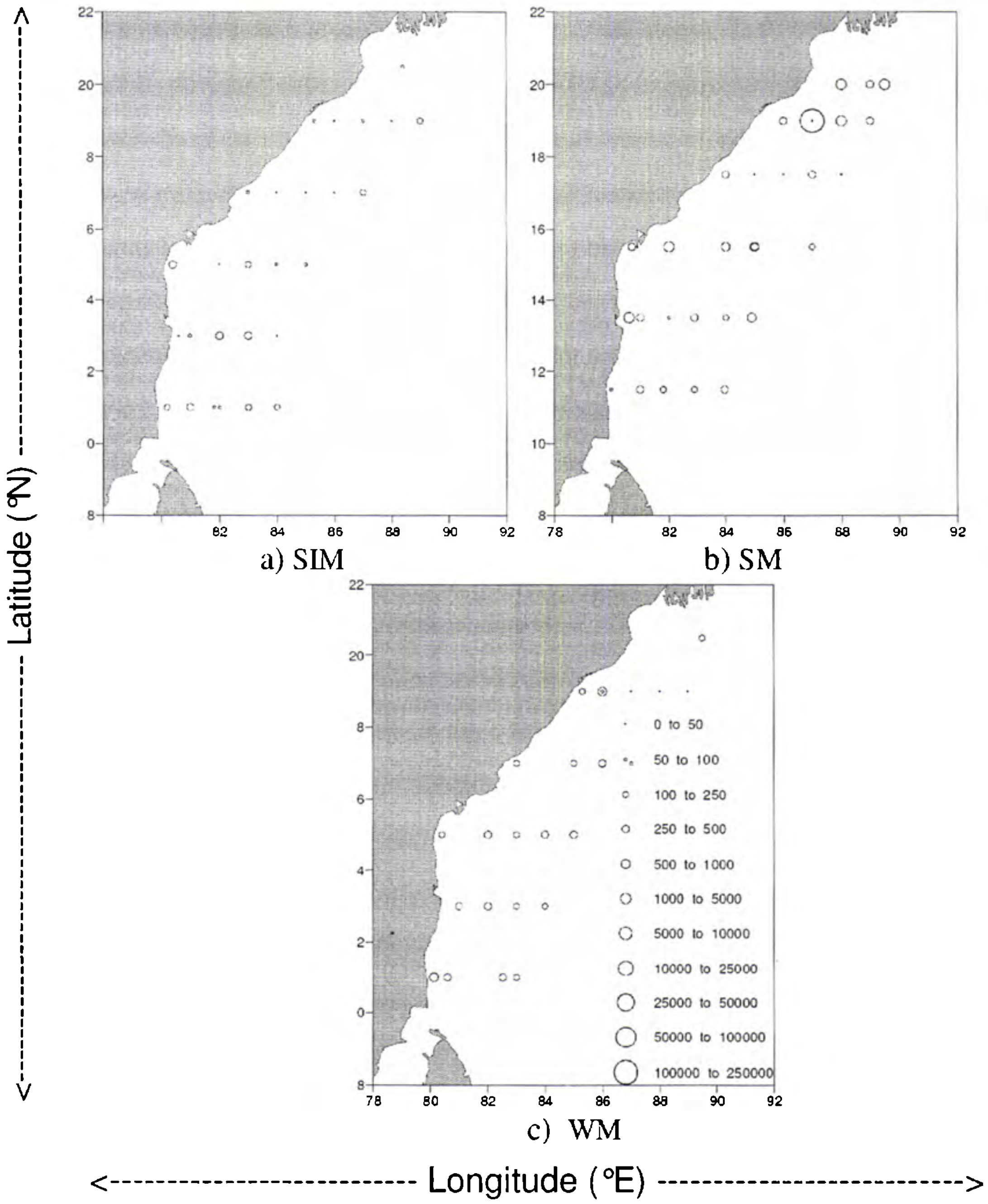


Fig.7.2 Spatial distribution of ostracod abundance in the Thermocline layer of the Bay of Bengal during different seasons a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

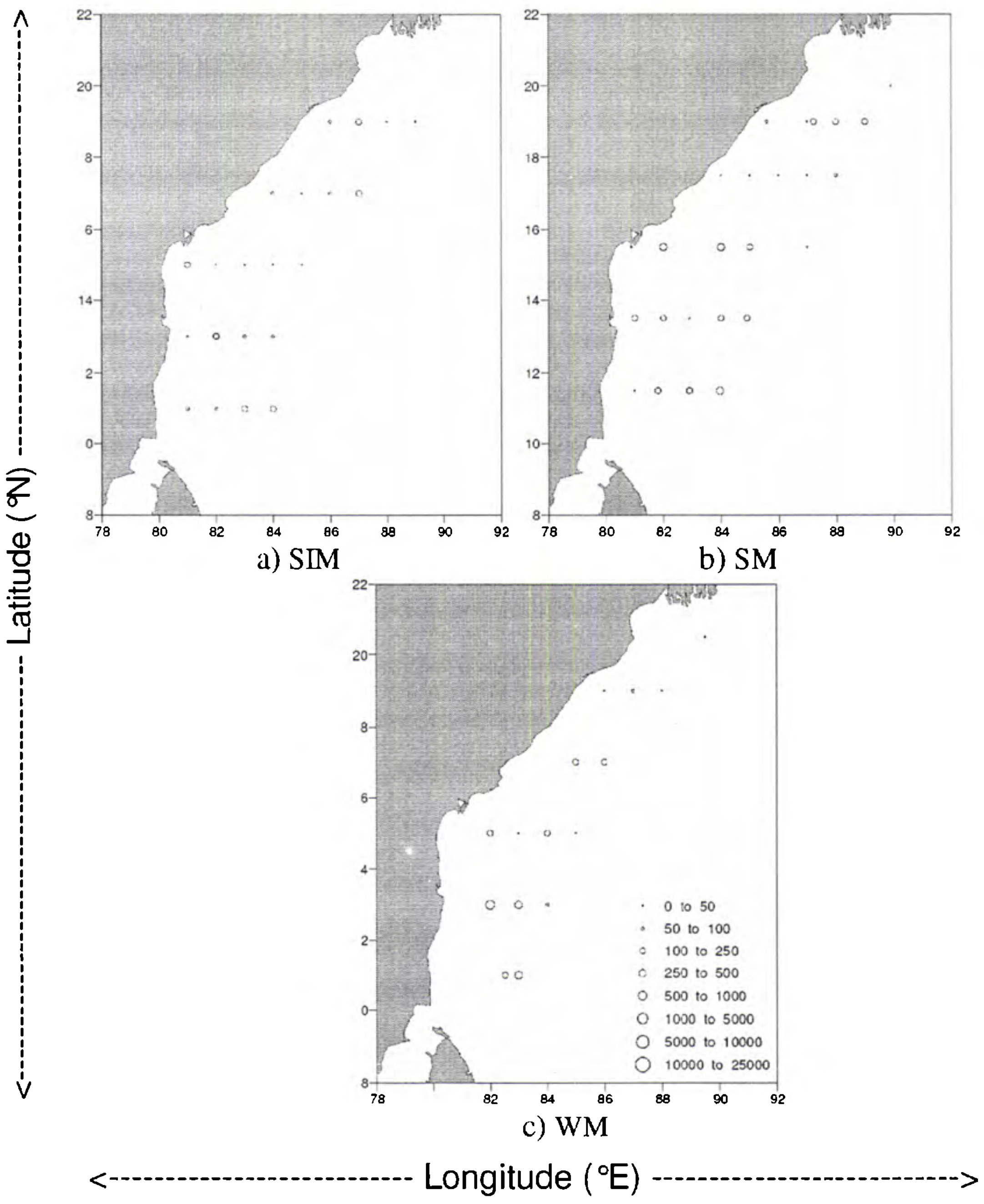
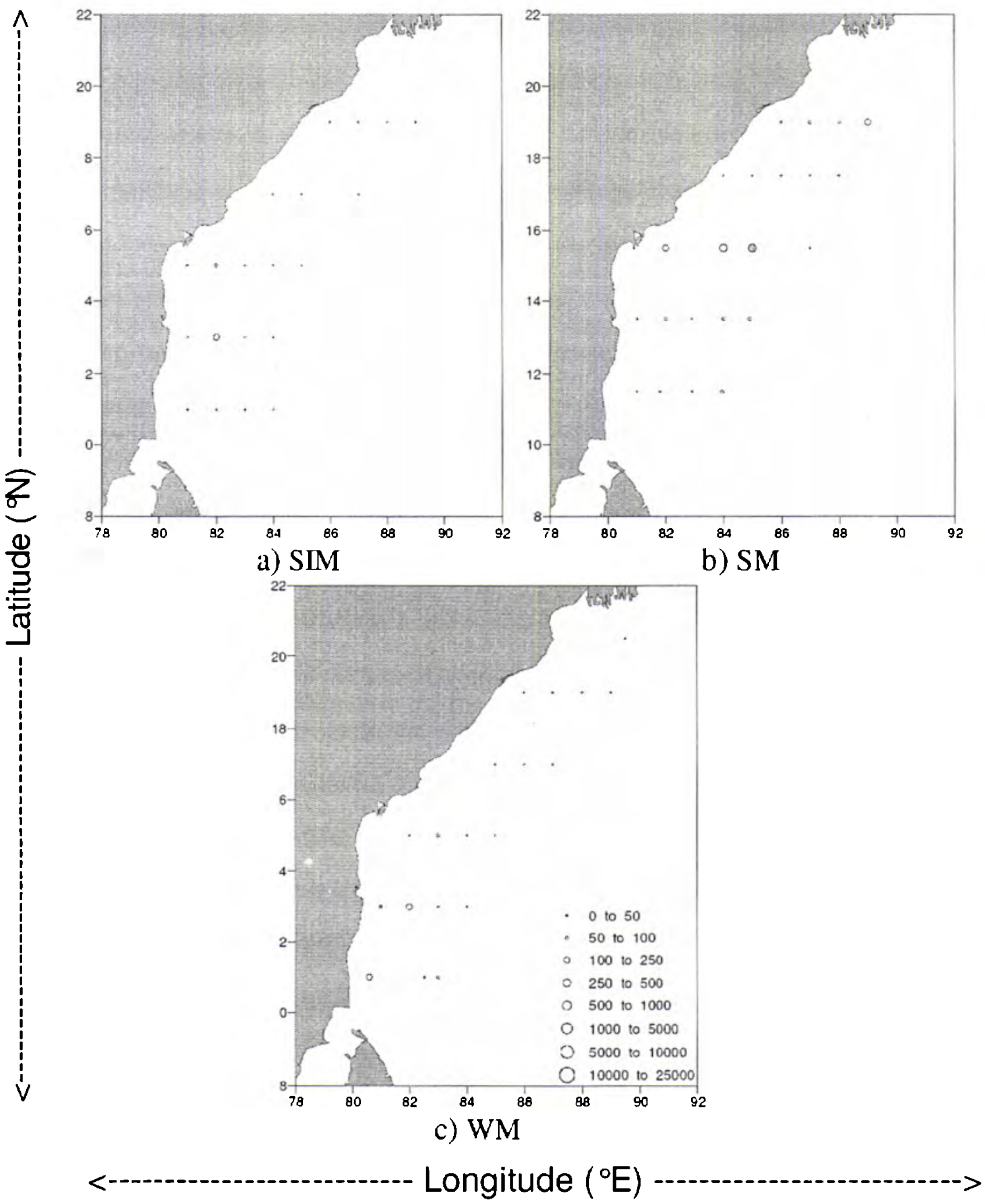


Fig.7.3 Spatial distribution of ostracod abundance in the 300-BT layer of the Bay of Bengal during different seasons a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.



a) SIM

b) SM

c) WM

Fig.7.4 Spatial distribution of ostracod abundance in the 500-300 layer of the Bay of Bengal during different seasons a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

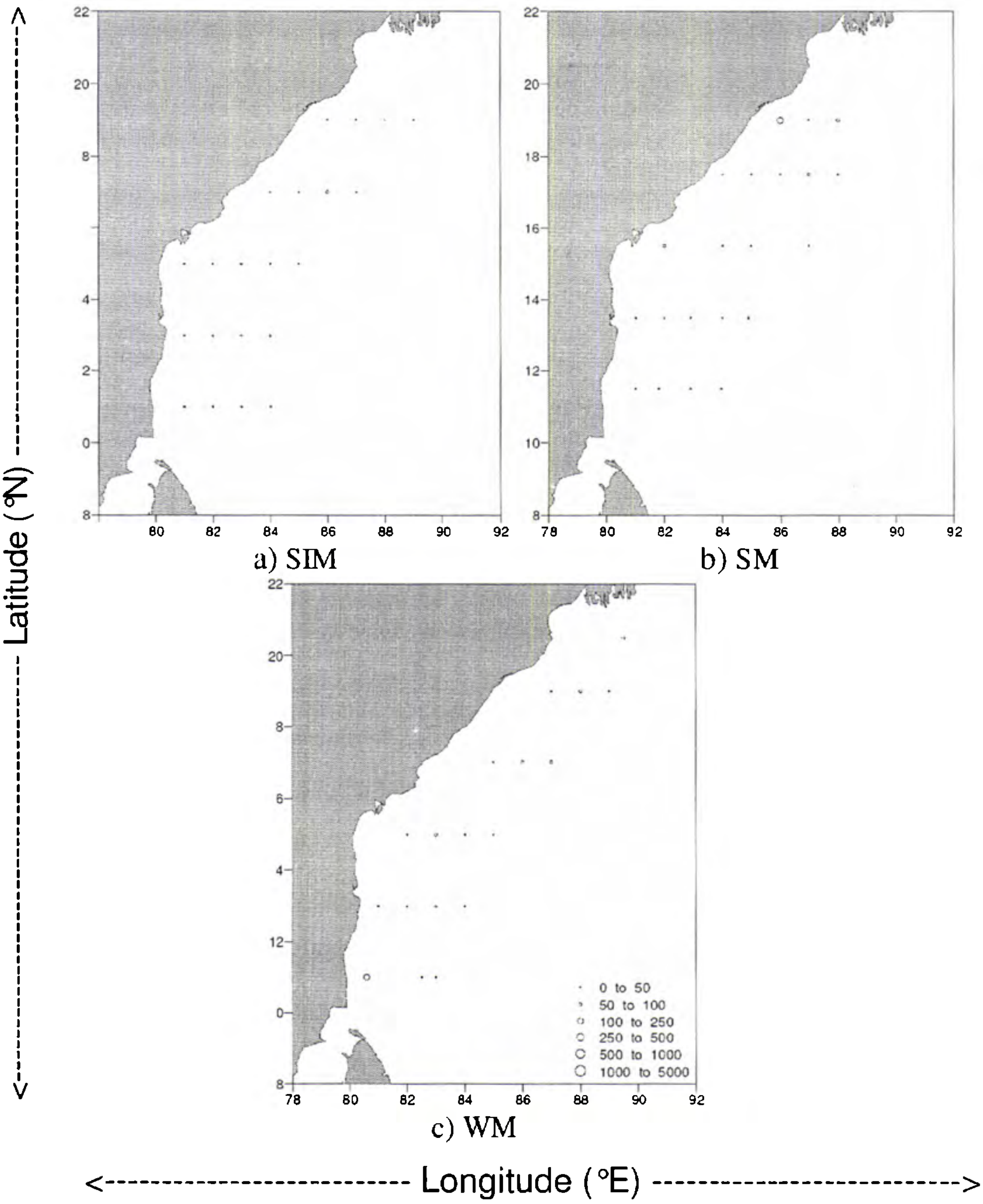


Fig.7.5 Spatial distribution of ostracod abundance in the 1000-500 layer of the Bay of Bengal during different seasons a) Spring intermonsoon b) Summer monsoon c) Winter monsoon.

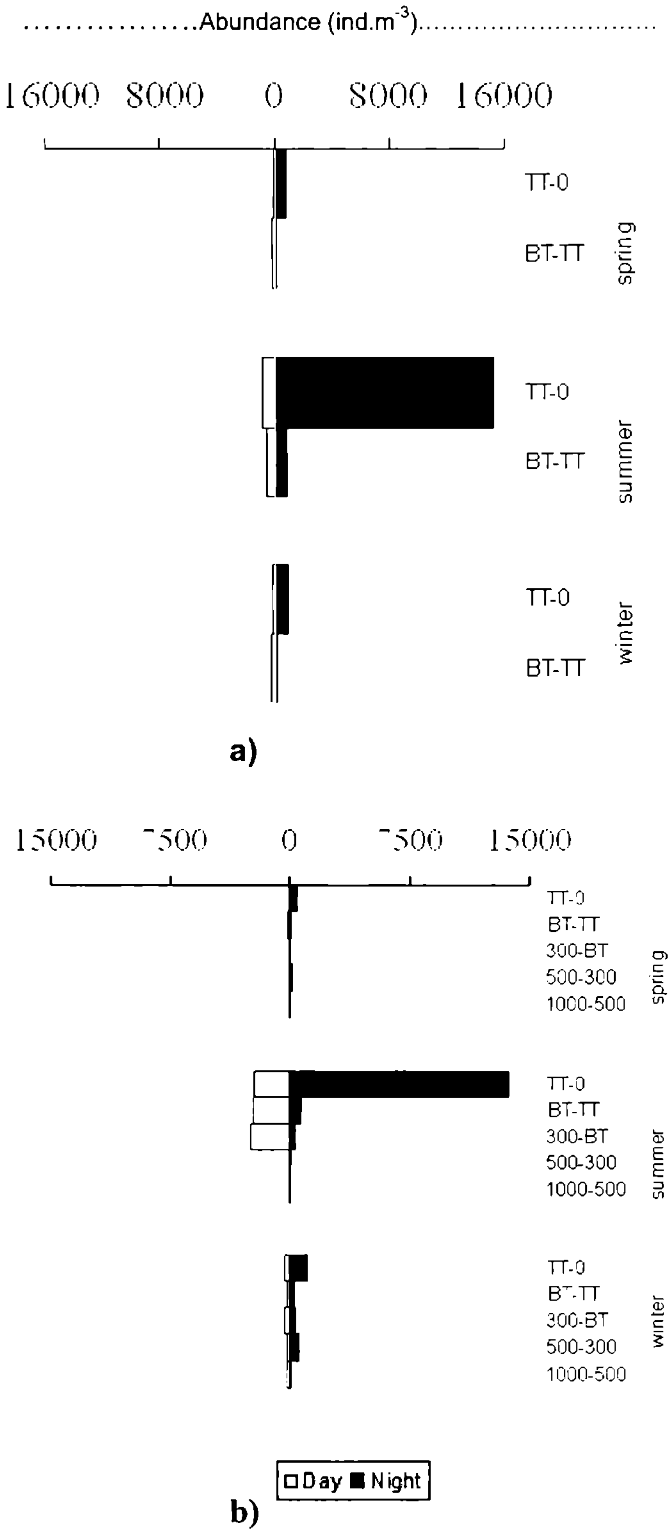


Fig.7.6 Day night variation of ostracods in a) Coastal and b) Oceanic stations of the Bay of Bengal during different seasons.

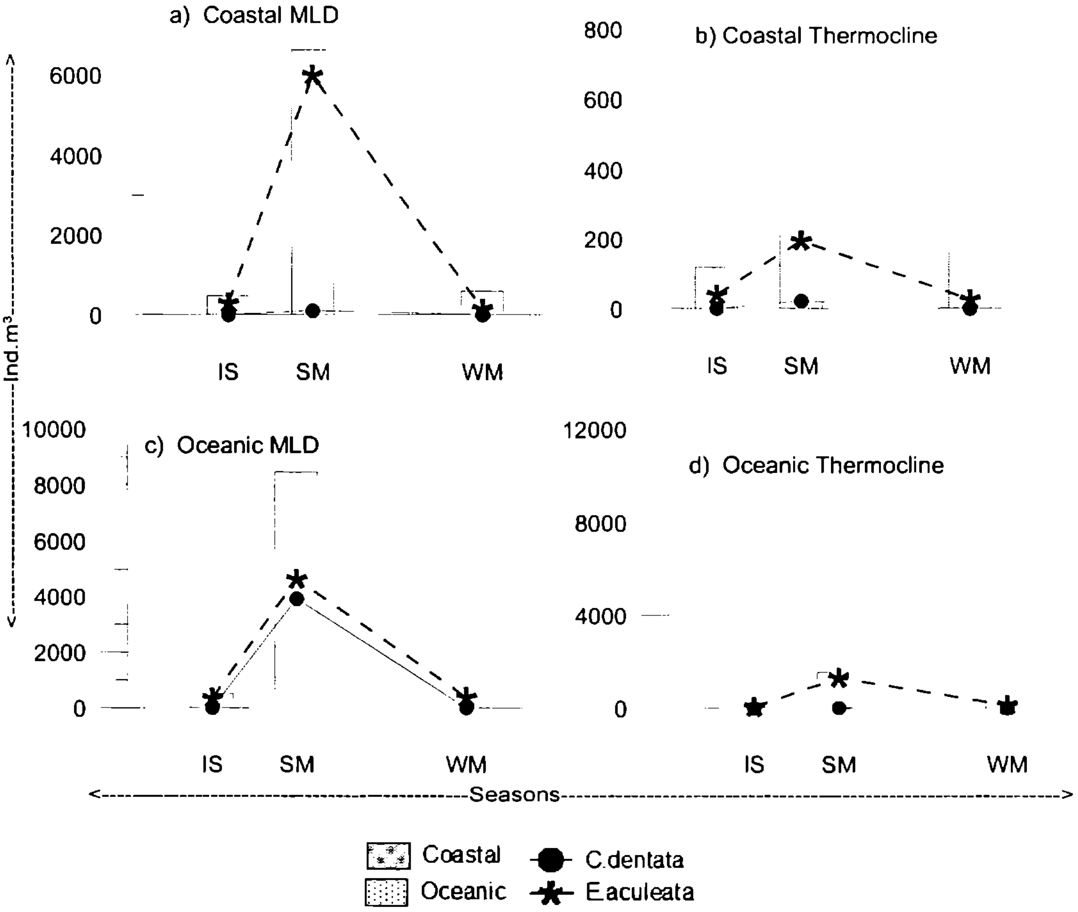


Fig.7.7 Distribution of *C.dentata* and *E.aculeata* in the coastal (a)Mixed layer (b)Thermocline and oceanic (c) Mixed layer (d)Thermocline during various seasons of the Bay of Bengal.

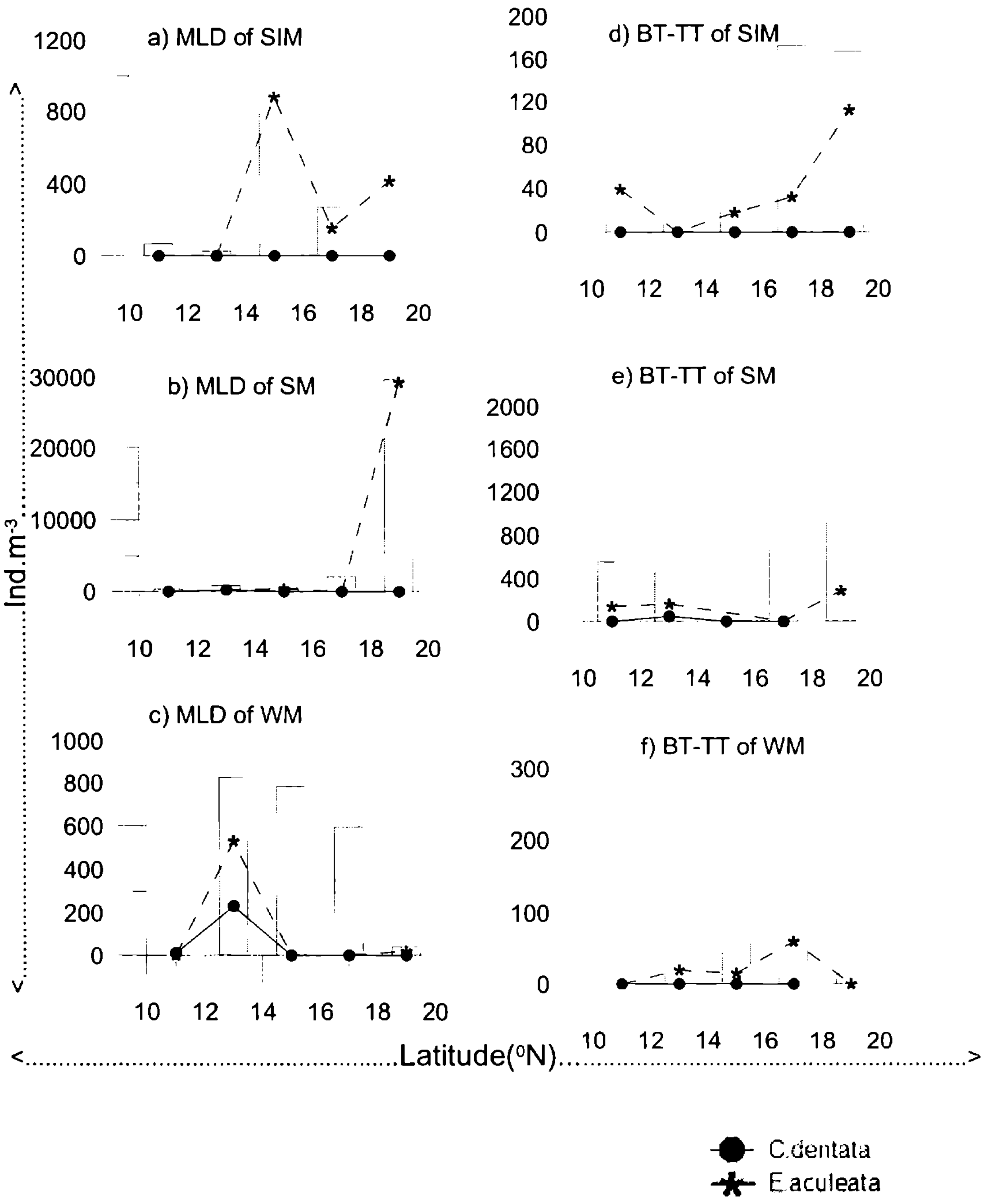


Fig.7.8 Latitudinal distribution of *C.dentata* and *E.aculeata* during different seasons of the BoB coastal stations (a) to (c) Mixed layer and (d) to (f) Thermocline.

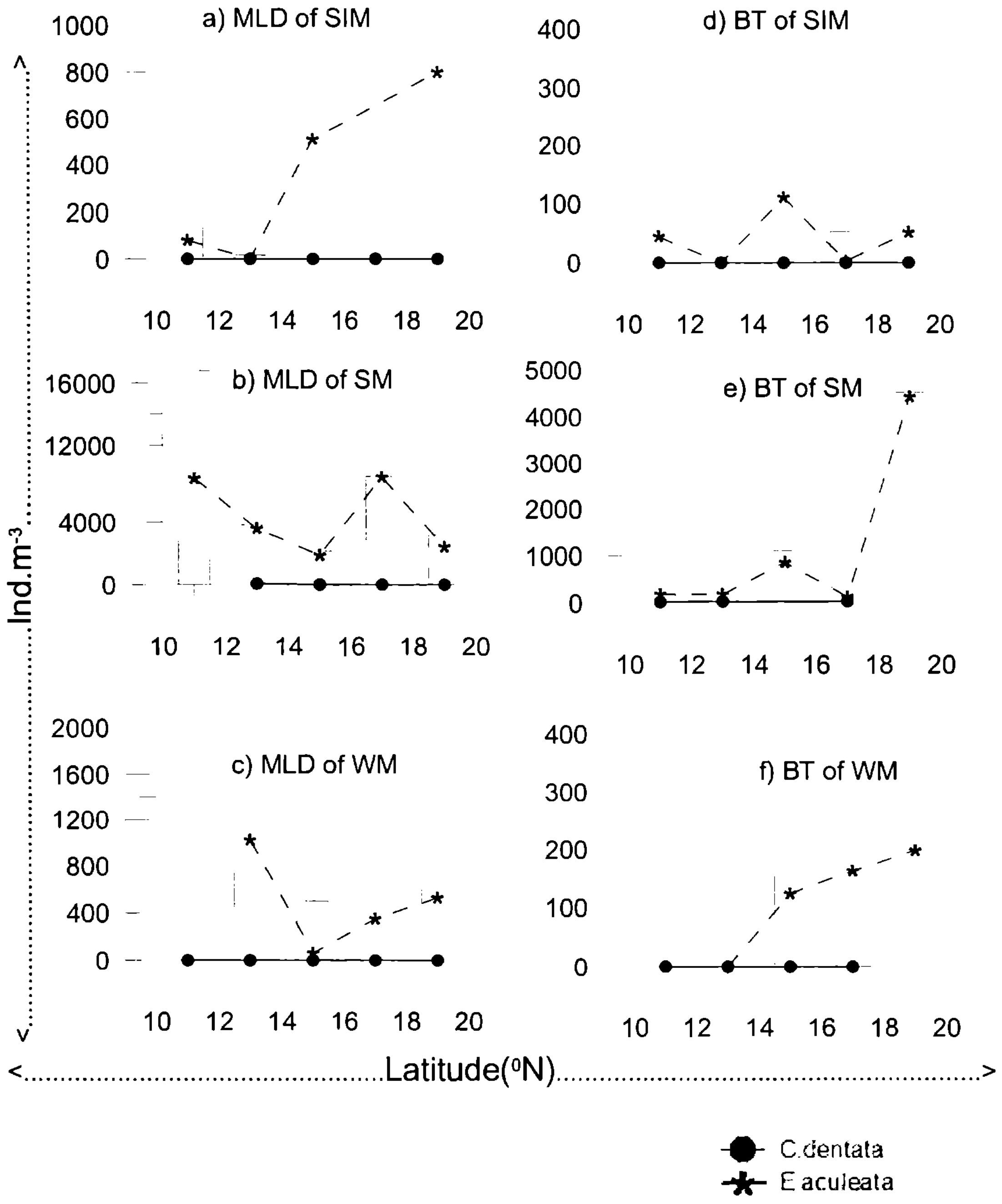


Fig.7.9 Latitudinal distribution of *C.dentata* and *E.aculeata* during different seasons of the BoB Oceanic stations (a) to (d) Mixed layer and (d) to (f) Thermocline.

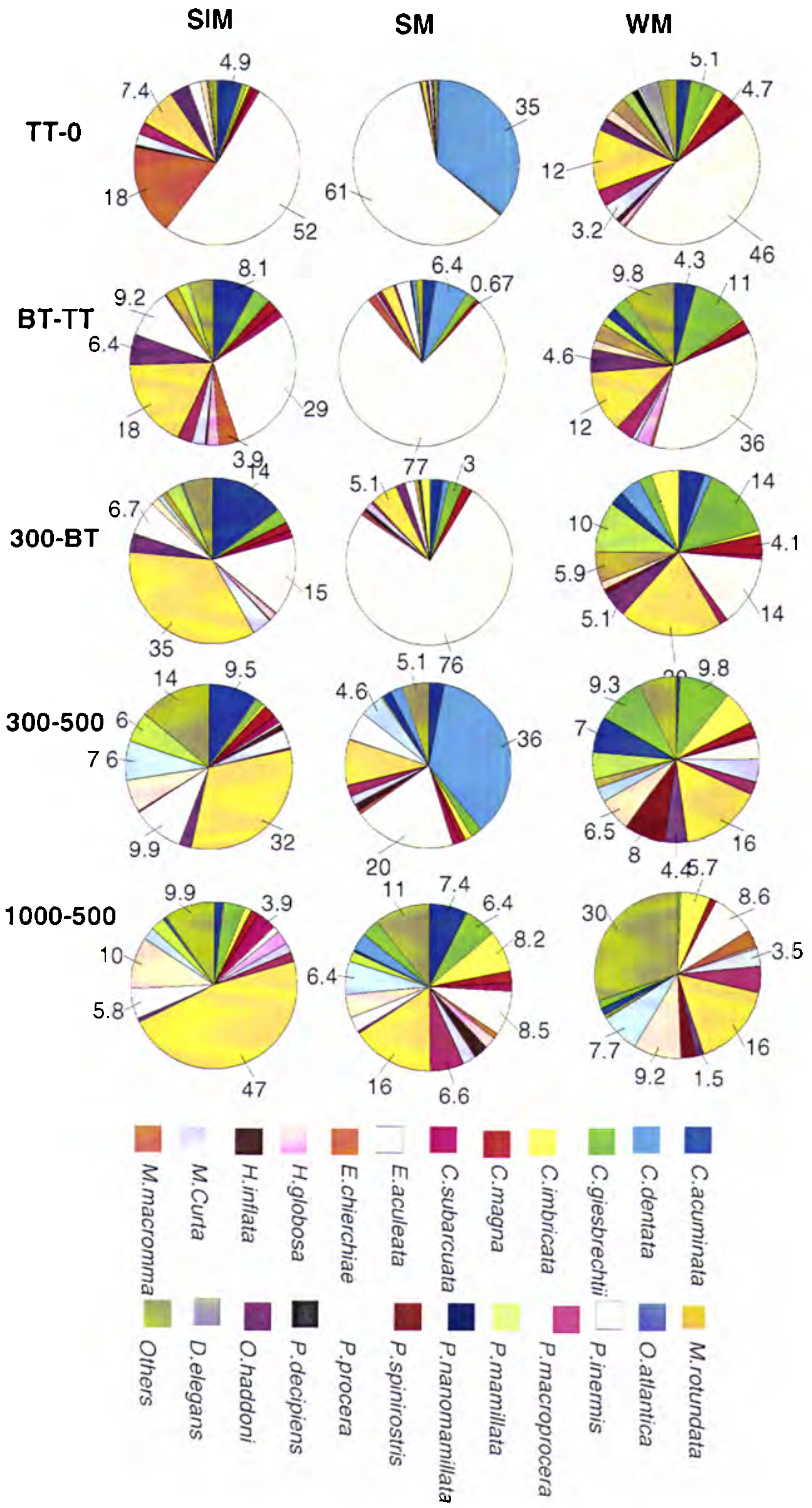


Fig.7.10 Seasonal variation of ostracod species in the Bay of Bengal at different depth layers.

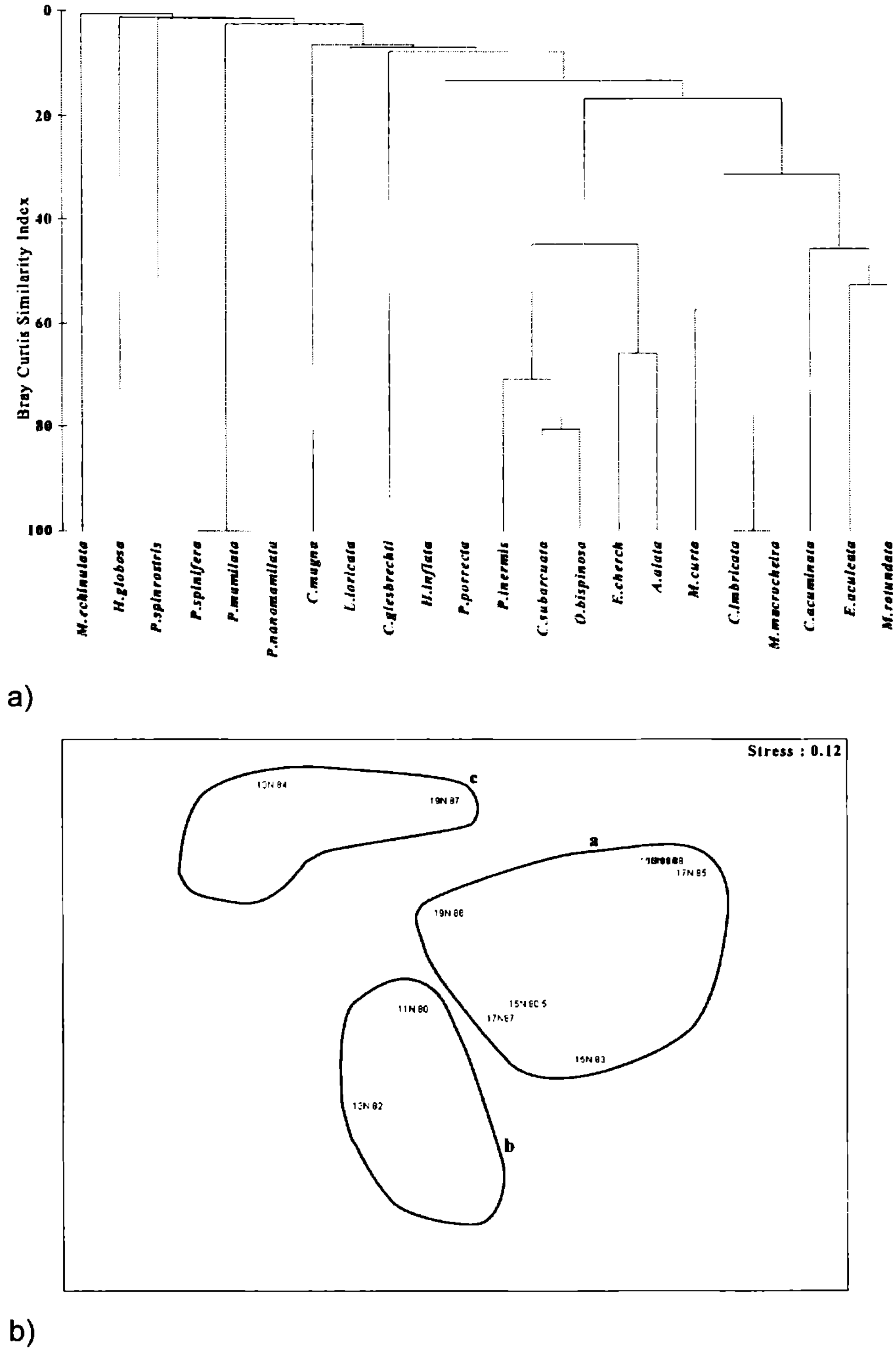


Fig 7.11 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the BoB during spring intermonsoon.

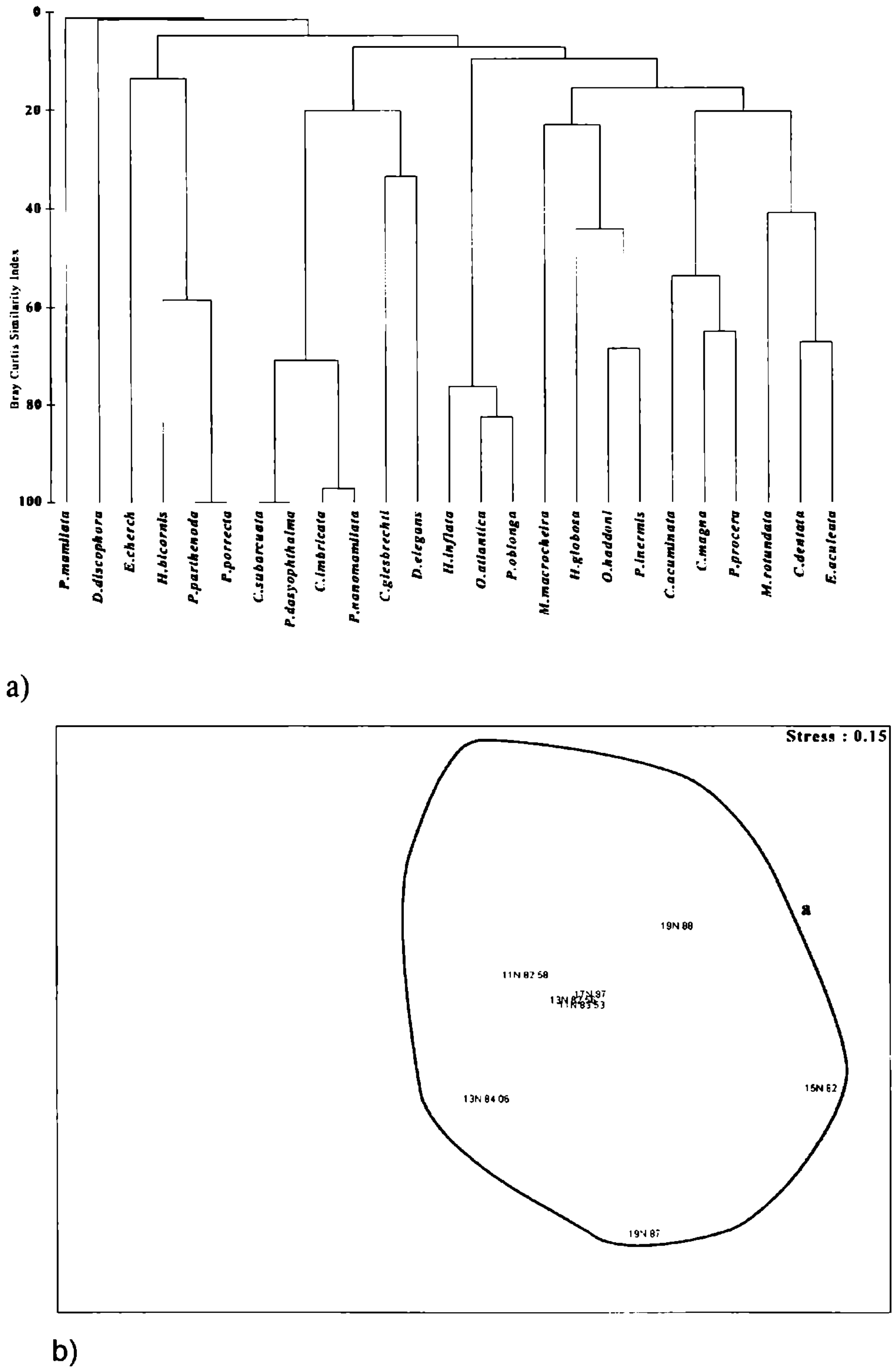


Fig7.12 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the BoB during summer monsoon.

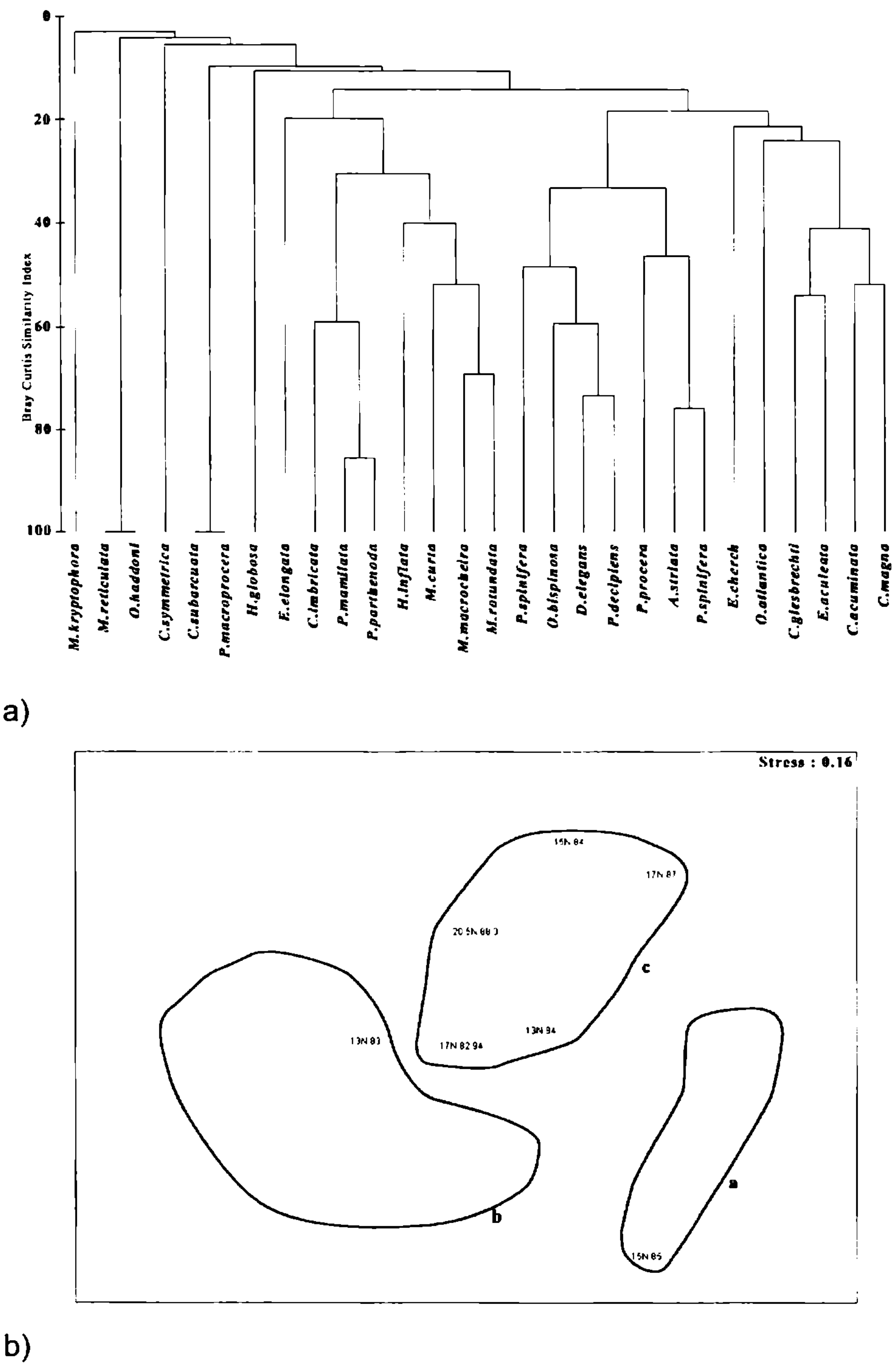


Fig7.13 (a)Dendrogram demonstrating clusters of the ostracod species (b) nMDS of the stations based on ostracod species abundance in the mixed layer of the BoB during winter monsoon.

Table. 7.1 Mean abundance of the planktonic ostracod species (ind.m^{-3}) during different seasons in the Bay of Bengal
$\overline{X}$ ' denotes the mean abundance, ' σ ' denotes standard deviation and ' C.V' represents coefficient of variation

Species (Ind.m-3)	**Spring Inter Monsoon**			**Summer Monsoon**			**Winter Monsoon**		
	$\overline{X}$	σ	C V	$\overline{X}$	σ	C.V	$\overline{X}$	σ	C.V
Alacia alata (Muller,1894)	0.00	0.00	0.00	0.00	0.00	0.00	0.55	2.99	540.07
Archiconchoecissa cucullata (Brady,1902) *	0.08	0.79	938.57	0.00	0.00	0.00	0.07	0.58	808.33
Archiconchoecia striata (Muller,1894)	0.00	0.00	0.00	0.00	0.00	0.00	0.64	2.94	455.59
Bathyconchoecia angeli (George,1977)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conchocetta acuminata (Claus,1890)	11.18	31.55	282.17	19.11	36.13	189.07	8.50	29.56	347.72
Conchoecilla chuni (Muller,1906)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conchoecilla daphnoides (Claus,1874) *	0.06	0.79	1307.67	0.00	0.00	0.00	0.05	0.33	734.89
Cypridina dentata (Muller,1906)	0.00	0.00	0.00	612.87	3834.56	625.68	0.37	3.75	1000.00
Conchoecetta giesbrechtii(Muller,1906)	3.15	13.60	431.26	18.85	52.54	278.80	19.02	38.04	199.95
Conchoecissa imbricata (Brady,1880)	0.75	8.37	1122.72	2.15	9.40	436.64	4.48	31.83	710.70
Conchoecia magna (Claus,1874)	2.16	9.78	452.02	7.48	22.80	304.85	11.28	52.28	463.28
Conchoecia parvidentata (Muller,1906)	0.00	0.00	0.00	0.46	2.23	480.34	0.23	1.17	502.58
Conchoecissa plinthina (Muller,1906) *	0.38	2.55	669.98	0.00	0.00	0.00	0.19	0.98	504.57
Conchoecia subarcuata (Claus,1890)	2.40	13.64	569.41	1.30	5.87	450.24	1.73	13.37	771.19
Conchoecissa symmetrica (Muller,1906)	0.00	0.06	1307.67	0.00	0.00	0.00	0.25	2.53	1000.00
Discoconchoecia discophora (Muller,1906)	0.07	0.95	1307.67	0.43	2.97	686.47	0.22	1.52	690.90
Discoconchoecia elegans(Muller,1906)	0.02	0.21	1307.67	1.04	5.31	510.70	9.64	37.22	386.00
Euconchoecia aculeata (Scott,1894)	64.26	214.91	334.45	1402.91	5819.01	414.78	108.19	316.68	292.71
Euchonchoecia chierchiae (Muller,1890)	18.57	133.47	718.77	9.43	43.82	464.84	1.23	8.18	667.35
Euchonchoecia elongata (Muller,1894)	0.00	0.00	0.00	0.00	0.00	0.00	0.24	2.38	1000.00
Felia bicornis (Muller,1906) *	0.08	0.63	776.82	5.10	24.37	477.58	0.09	0.91	1000.00
Halocypris brevirostris (Dana,)	0.40	2.73	675.74	0.00	0.00	0.00	0.04	0.40	1000.00
Halocypria globosa (Claus,1874)	1.33	6.46	485.63	2.52	12.08	479.30	3.38	17.40	514.78
Halocypris inflata (Dana,1849)	0.67	5.59	839.01	4.13	27.91	675.04	1.77	10.83	612.44

Loricoecia loricata (Claus,1894) *	0.05	0.71	1307.67	0.00	0.00	0.00	0.00	0.00	0.00
Mikroconchoecia acuticosta (Muller,1906) *	0.00	0.00	0.00	0.04	0.47	1058.30	0.12	1 17	1000.00
Macroconchoecia caudata (Muller,1906) *	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
Mikroconchoecia curta (Lubbock,1860)	4.12	21.39	519.50	3.45	13.55	392.69	7.09	31 70	446.88
Mikroconchoecia echinulata (Claus,1891) *	0.17	2.27	1307.67	0.07	0.62	870.85	0.24	1.82	768.99
Metaconchoecia pusilla (Angel,1971) *	0.00	0.00	0.00	0.00	0.00	0.00	0.28	1.64	591.65
Metaconchoecia krytophora(Angel,1971) *	0.21	1.84	867.29	0.40	2.49	616.14	0.56	2.34	419.08
Conchoecia macrocheira (Muller,1906) *	3.57	32.31	903.91	4.70	15.54	330.84	8.85	27.41	309.73
Metaconchoecia obtusa (Goodday,1981)	0.03	0.42	1307.67	0.36	2.19	606.33	0.37	2.42	650.33
Macroconchoecia reticulata (Muller,1906) *	0.01	0.18	1307.67	0.14	1.02	756.39	1.60	15.84	990.05
Metaconchoecia rotundata (Muller,1890)	24.60	46.27	188.12	36.17	96.17	265.88	35.68	66.98	187.69
Mikroconchoecia stigmatica (Muller,1906) *	0.00	0.00	0.00	0.02	0.24	1058.30	0.03	0.34	1000.00
Orthoconchoecia atlantica (Lubbock,1856)	7.12	24.06	338.10	13.08	90.49	691.82	8.15	32.86	403.24
Orthoconchoecia bispinosa (Claus,1890)	0.76	7.42	976.37	0.08	0.89	1058.30	3.59	18.81	523.25
Orthoconchoecia haddoni (Brady &Norman,1896)	0.15	1.27	850.62	6.12	24.64	402.47	2.14	13.29	620.86
Pseudoconchoecia concentrica (Muller,1906)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paraconchoecia cophopyga (Muller,1906) *	0.21	2.71	1307.67	0.05	0.57	1058.30	0.05	0.34	736.29
Paraconchoecia dasyophthalma (Muller,1906) *	0.16	1.23	772.67	0.95	3.22	339.87	0.07	0.49	710.72
Paraconchoecia decipiens (Muller,1906)	0.03	0.37	1307.67	1.12	5.29	473.43	4.83	16.52	342.10
Paraconchoecia dorsotuberculata (Muller,1906) *	0.10	1.27	1307.67	0.00	0.00	0.00	0.00	0.00	0.00
Paraconchoecia inermis (Claus,1890)	8.11	24.70	304.72	22.87	59.49	260.15	0.00	0.00	0.00
Proceroecia macroprocera (Angel,1971)	0.13	1.40	1094.22	0.00	0.00	0.00	1.58	7.85	496.57
Paraconchoecia mamillata (Muller,1906) *	2.40	16.66	694.85	0.89	6.13	686.68	6.10	31.44	515.76
Paraconchoecia nanomamillata (Deevey,1980)*	0.89	3.38	379.96	3.36	13.88	413.08	0.70	2.87	408.92
Paraconchoecia oblonga (Claus,1890)	0.33	3.51	1060.59	3.42	22.00	643.51	0.18	1.07	597.37
Porroecia parthenoda (Muller,1906)	1.42	6.22	438.98	3.86	29.95	776.14	4.41	13.77	312.28
Porroecia porrecta (Claus,1890)	0.09	0.99	1143.31	4.04	28.67	709.29	0.27	1.68	633.28
Proceroecia procera (Muller,1894)	2.40	9.29	386.74	3.31	21.21	640.66	7.41	21.18	286.07
Platyconchoecia prosadene (Muller,1906)	0.00	0.00	0.00	0.27	2.21	832.82	0.24	1.37	575.17
Paraconchoecia spinifera (Claus,1891)	0.70	3.92	558.49	0.09	0.69	761.83	0.26	1.50	585.11
Porroecia spinirostris (Claus,1874)	1.49	7.86	527.18	1.42	12.42	873.79	8.79	35.02	398.57
Total ostracod	165.06	342.22	207.33	2252.31	7961.16	353.47	279.24	417.63	149.56

Table. 7.2 Ostracod species distribution in the coastal and oceanic stations of the mixed layer of the Bay of Bengal during different seasons.

Species(ind.m^{-3})		IntermonsoonSpring		Summermonsoon		Wintermonsoon	
		MLD					
		Coastal	Open	Coastal	Open	Coastal	Open
1	*A. striata*	0.02	0.00	0.00	0.00	1.82	1.01
2	*C. giesbrechtii*	0.00	10.32	79.28	7.27	18.00	32.56
3	*C. imbricata*	10.91	0.00	0.00	11.60	29.09	0.00
4	*C. magna*	7.86	0.00	0.00	18.35	3.64	57.53
5	*C. subarcuata*	1.62	0.00	0	2.91	12	0.00
6	*C. symmetrica*	0.00	0.00	0.00	0	0.00	2.32
7	*C.acuminata*	31	23	0.00	39.37	7.40	35
8	*C.dentata*	0.00	0.00	105.52	3924	0.00	0.00
9	*C.macrocheira*	38.18	0.00	0.00	0.00	31.55	26.39
10	*D. discophora*	0.00	0.00	0.00	1.62	0.00	0.00
11	*D.elegans*	0.00	0.00	0.00	0.91	53.01	2.91
12	*E. aculeata*	290	348	5997	4645	148	381
13	*E. chierchiae*	10.09	85.75	337.56	9.85	0.00	7.07
14	*E. elongata*	0.00	0.00	9.68	0.00	2.18	0.00
15	*F. bicornis*	0.00	0.00	0.00	11.17	0.00	0.00
16	*H. globosa*	1.95	0.00	0.00	3.12	0.00	18.91
17	*H. inflata*	3.33	0.00	0.00	0.00	1.86	14.37
18	*L. loricata*	0.00	0.78	0.00	0.00	0.00	0.00
19	*M. curta*	27.73	2.33	0.00	0.00	16.99	15.76
20	*M. rotundata*	34.47	28.10	2.76	33.35	75.16	114.72
21	*M. stigmatica*	0.00	0.00	102.88	0.00	0.00	0.00
22	*O. atlantica*	13.64	7.32	0.00	0.00	20.91	19.19
23	*O. bispinosa*	0.00	0.00	0.00	0.00	21.26	0.00
24	*O. haddoni*	0.00	0.00	0.00	20.78	0.00	0.00
26	*P. concentrica*	0.00	0.00	1.94	0.00	0.00	0.00
26	*P decipiens*	0.00	0.00	0.00	0.00	8.48	5.18
27	*P. inermis*	1.62	10.12	40.00	33.25	0.00	0.00
28	*P macroprocera*	0.00	0.00	7.10	0.00	5.45	0.00
30	*P parthenoda*	0.00	0.00	0.00	0.00	16.27	0.00
31	*P. procera*	4.00	0.00	0.00	19.83	31.13	3.31
32	*P. spinifera*	0.00	0.00	0.00	0.00	1.21	0.00
33	*P.dasyophthalma*	0.00	0.00	0.00	1.16	0.00	0.00
34	*P.mamillata*	0.00	0.00	6.00	0.00	34.79	0.00
35	*P.nanomamillata*	0.00	0.00	0.00	17.16	0.00	0.00
36	*P.spinirostris*	0.00	0.00	0.00	0.00	39.09	10.04

Table. 7.3 Mean abundance of ostracod species during day and night in the mixed layer and thermocline of the coastal stations of the Bay of Bengal during all seasons.

Species ($ind.m^{-3}$)	Inter monsoon spring				Summer monsoon				Winter monsoon			
	Mixed Layer		Thermocline		Mixed Layer		Thermocline		Mixed Layer		Thermocline	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
A.striata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	3.03	0.00
C.acuminata	6.07	35.88	14.95	3.55	0.00	0.00	40.07	0.00	13.62	2.22	3.70	5.36
C.dentata	0.00	0.00	0.00	0.00	189.94	0.00	44.38	0.00	0.00	0.00	0.00	0.00
C.giesbrechtii	0.00	0.00	9.74	2.86	87.63	54.22	25.07	44.71	5.33	28.55	7.91	9.35
C.imbricata	0.00	13.64	0.00	0.00	0.00	0.00	0.00	40.25	0.00	53.33	0.00	0.00
C.magna	0.00	16.07	4.90	7.53	0.00	0.00	26.50	0.00	0.00	6.67	1.68	0.00
C.subarcuata	5.41	0.00	5.25	0.27	0.00	0.00	8.50	0.00	0.00	22.22	0.00	0.00
D.elegans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.18	32.51	0.00
E.aculeata	38.25	592.66	40.05	21.95	555.87	14157.50	346.62	6.88	15.33	258.89	22.55	29.72
E.cherchii	0.00	25.22	1.29	2.86	0.00	1012.68	0.00	482.47	0.00	0.00	0.00	4.20
H.inflata	0.00	8.33	0.00	0.00	0.00	0.00	1.50	6.25	0.00	3.42	0.00	0.00
M.curta	10.81	33.94	0.00	1.40	0.00	0.00	4.50	0.00	14.40	19.15	2.31	1.40
M. procera	0.00	47.73	0.00	0.00	0.00	0.00	0.00	0.00	3.20	55.17	11.40	7.74
M.rotudata	16.66	48.18	12.82	20.38	4.60	0.00	39.49	1.56	41.91	102.86	37.51	22.83
O.atlantica	6.50	14.58	6.04	12.58	0.00	0.00	0.00	0.00	0.00	38.33	7.91	0.93
P.inermis	5.41	0.00	12.68	2.45	66.67	0.00	18.35	0.00	0.00	0.00	0.00	0.00
P.procera	0.00	10.00	4.85	1.59	0.00	0.00	7.00	15.45	29.51	32.48	0.77	0.92

Table. 7.4 Mean abundance of ostracod species during day and night in the different depth layers of the oceanic stations of Bay of Bengal during Spring intermonsoon.

Species	**Inter monsoon spring**							
	Mixed Layer		**Thermocline**		**300-BT**	**500-300**		**1000-500**
(ind.m^{-3})	**Day**	**Night**	**Day**	**Night**	**Day**	**Day**	**Night**	**Day**
C.acuminata	2.61	26.71	15.63	19.12	0.00	12.00	12.54	0.00
C.giesbrechtii	0.00	16.81	4.46	6.09	9.09	0.00	3.68	0.00
C.magna	0.00	0.00	0.56	0.82	0.00	0.00	2.93	0.00
E.aculeata	0.95	293.70	19.35	44.75	0.00	0.00	80.04	0.00
E.cherchii	0.00	95.59	4.83	0.00	0.00	0.00	18.58	0.00
M.Curta	0.00	3.10	0.00	0.61	21.21	0.00	4.31	0.00
M.rotudata	0.00	15.25	8.62	32.79	21.21	0.00	25.06	23.20
O.atlantica	0.00	12.14	8.65	5.35	0.00	0.00	7.98	0.00
O.bispinosa	0.00	0.00	0.00	0.58	0.00	0.00	0.67	0.00
O.haddoni	0.00	0.00	0.00	1.45	0.00	0.00	0.12	0.00
P.inermis	0.00	17.99	9.33	3.45	0.00	6.00	7.82	1.60
P.oblonga	0.00	0.00	0.00	4.55	0.00	0.00	0.48	0.00
P.parthenoda	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00
P.porrecta	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00
P.procera	0.00	0.00	0.00	0.48	12.12	0.00	2.68	2.40

Table.7.5 Mean abundance of ostracod species during day and night in the different depth layers of the oceanic stations of the Bay of Bengal during Summer monsoon.

Species (ind.m^{-1})	**Summer monsoon**									
	TT-o		**BT-TT**		**300-BT**		**500-300**		**1000-500**	
	Day	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
C.acuminata	55.06	26.29	28.92	35.48	7.90	32.99	8.00	1.00	2.20	4.60
C.dentata	0.00	7848	15.60	5.68	22.47	5.33	0.00	0.00	0.00	0.00
C.giesbrechtii	16.00	0.00	15.70	43.94	42.59	16.72	3.00	0.00	1.00	3.20
C.magna	40.36	0.00	7.91	8.44	13.33	13.11	0.00	2.50	3.40	0.00
E.aculeata	1822.90	6996.19	2086.79	406.54	2271.98	107.90	0.00	2.50	6.20	4.60
E.cherchii	21.67	0.00	4.40	10.75	0.00	0.00	0.00	0.00	0.00	0.00
M.Curta	0.00	0.00	0.00	8.23	0.00	16.74	0.00	1.50	0.00	4.20
M.rotudata	37.45	29.93	23.21	60.94	24.57	72.26	16.50	8.00	2.00	6.40
O.atlantica	0.00	0.00	2.20	15.05	17.65	41.80	0.00	0.00	0.00	1.40
O.bispinosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O.haddoni	45.71	0.00	3.96	20.48	0.00	2.96	0.00	0.00	0.00	0.00
P.inermis	73.14	0.00	29.20	42.29	42.22	7.46	6.50	11.00	0.00	1.80
P.oblonga	4.00	0.00	0.00	11.79	16.67	0.00	0.00	0.00	0.00	0.00
P.parthenoda	0.00	0.00	0.00	0.00	0.00	1.48	6.00	1.50	0.00	2.80
P.porrecta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P.procera	43.64	0.00	0.00	4.62	0.00	0.00	0.00	0.00	1.00	0.00

Table.7.6 Mean abundance of ostracod species during day and night in the different depth layer of the oceanic stations of the Bay of Bengal during Winter monsoon.

Species (ind.m^{-3})	**Winter monsoon**									
	TT-o		**BT-TT**		**300-BT**		**500-300**		**1000-500**	
	Day	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
C.acuminata	22.40	45.37	1.4286	26.466	4.48	16.39	1.79	16.52	1.79	0.00
C.giesbrechtii	6.40	54.35	25	43.796	26.06	49.18	10.74	20.26	10.74	0.00
C.magna	18.11	90.37	5.0314	8.6015	2.99	22.95	1.19	17.28	1.99	0.00
E.aculeata	180.07	547.76	106.37	147.61	0.00	0.00	0.00	337.36	0.00	0.00
E.cherchii	0.00	12.96	0	0	0.00	0.00	0.00	0.00	0.00	0.00
M.Curta	0.00	28.89	0	0	0.00	0.00	0.00	19.26	0.32	0.00
M.rotudata	62.98	157.83	20.714	18.581	61.54	216.39	32.14	59.64	29.42	11.20
O.atlantica	5.33	30.74	6.4286	0	60.00	0.00	24.40	17.32	24.40	4.80
O.bispinosa	0.00	0.00	0	17.6	0.00	0.00	0.00	9.78	0.00	0.00
O.haddoni	0.00	0.00	0	0	23.08	55.74	9.23	6.19	9.23	0.00
P.inermis	0.00	0.00	0	0	0.00	0.00	0.00	0.00	0.00	0.00
P.oblonga	0.00	0.00	1.4286	0	0.00	0.00	0.00	0.00	0.00	0.00
P.parthenoda	0.00	0.00	2.1429	7.8195	0.00	0.00	1.44	4.34	1.44	0.00
P.porrecta	0.00	0.00	2.1429	0	0.00	0.00	0.00	0.00	0.00	0.00
P.procera	7.27	0.00	0	0.6015	51.66	0.00	20.67	0.33	20.67	0.00

Table 7.7a 3 Way ANOVA for comparing between seasons, between day and night, between stations in different latitudes mesozooplankton biomass in the Mixed layer of the coastal stations of the Bay of Bengal.

Source	dof	Coastal Stations	
		F ratio	
		MLD	Thermocline
Seasons(A)	3	2.3489	1.1390
Day/Night(B)	1	1.0104	1.0776
Latitudes(C)	4	1.0372	1.0096
AB interaction	3	0.6871	1.0694
BC interaction	4	1.1440	1.0131
AC interaction	12	0.8951	0.9666
Error	12		
Total	39		

Table.7.7b 3 Way ANOVA for comparing between seasons, between day and night, between stations in different latitudes mesozooplankton biomass in the different depth layer of the oceanic stations of the Bay of Bengal.

Source	dof	Open stations				
		F ratio				
		MLD	Thermocline	300-BT	500-300	1000-500
Seasons(A).	3	1.3241	0.9747	4.7896*	1.0638	1.0010
Day/Night(B)	1	1.1453	0.9618	0.2198	0.6647	0.0683
Latitudes(C)	4	1.2099	1.0133	6.9959**	0.7559	2.8270[a]
AB interaction	3	0.8001	1.0123	0.5564	2.0449	3.5039*
BC interaction	4	1.0502	1.0146	4.8946*	0.8618	1.5326
AC interaction	12	1.2268	0.9995	3.2705*	1.0805	1.0625
Error	12					
Total	39					

dof - degree of freedom, F ratio- F static used for the test calculated F ratio is significant at (*) 5% level ($P < 0.05$), (**) at 1% level ($P < 0.01$), (a) at 7%level ($P < 0.07$)

Table.7.8a Two way nested ANOVA for comparing seasons based on ostracod species in the MLD and thermocline layer of the coastal stations.

DEPTH	Source	df	MSS	F ratio	R	C	R<C	$F_{S'}$	Remarks
MLD	**Among Seasons (groups)**	2	3575194.4	2.6823*				1.03112	(P>0.05)
	Among Species (subgroups)	39	3562785.63	2.6730**					
	Within subgroups(Stations)	159	1332872.34						
	Error	200	1790129						
	Total								
BT-TT	**Among Seasons (groups)**	2	71626.6016	6.3456	118.4698	1.6137		2.15	(P<0.15)
	Among Species (subgroups)	46	33831.7951	2.9972**					
	Within subgroups(Stations)	198	11287.6087						
	Error	246	15993.75						
	Total								

Table.7.8b Two way nested ANOVA for comparing seasons based on ostracod species in the MLD and thermocline layer of the oceanic stations.

DEPTH	**Source**	**df**	**MSS**	**F ratio**	**R**	**C**	**R<C**	**$F_{s'}$**	**Remarks**
MLD	**Among Seasons (groups)**	2	278498.78	7.9345	118.48	1.6929		2.0488	
	Among Species (subgroups)	39	132711.93	3.7810**					
	Within subgroups(Stations)	177	35099.69						
	Error	218	54795.45						
	Total								
BT-TT	**Among Seasons (groups)**	2	1062613	2.9439				0.9388	(P>0.05)
	Among Species (subgroups)	73	1127606	3.1248**					
	Within subgroups(Stations)	327	360947						
	Error	402	5037712						
	Total								
300-BT	**Among Seasons (groups)**	2	2667.39	18.4733				7.8338	(P<0.001)
	Among Species (subgroups)	44	340.49	2.3582**					
	Within subgroups(Stations)	175	144.39						
	Error	221	206.268						
	Total								
300-500	**Among Seasons (groups)**	2	1370.94	3.8249				3.7182	(P < 0.05)
	Among Species (subgroups)	48	368.44	1.0279					
	Within subgroups(Stations)	182	358.42						
	Error	232	369.224						
	Total								
500-1000	**Among Seasons (groups)**	2	40.4542	2.2759				1.92	(P < 0.05)
	Among Species (subgroups)	56	21.0663	1.1852^a					
	Within subgroups(Stations)	271	3857.15						
	Error								
	Total								

at 10%level

Table.7.9 Community structure indices for ostracod species in the different depth layers of the coastal regions of the Bay of Bengal during different seasons (Stations averaged). S- Number of Species, R- Margalef's richness Index, I- Simpson's Concentration Index, $H_{(s)}$ Shannon weaver's species diversity index, €- Heip's evenness Index, D- Pielou's index of species dominance.

Seasons	Depth	S	R	I	H(s)	€	D
SIM	MLD	4.500±2.646	0.569±0.385	0.4105±0.2855	1.1893± 0.8712	0.7911± 0.8031	0.4847±0 .355
	BT-TT	7.800±3.347	1.658±0.512	0.7367± 0.062	2.3133± 0.3867	1.5009 ±0.2371	0.8188± 0.1278
SM	MLD	4.800±3.114	0.460±0.358	0.1929± 0.2504	0.6048 ± 0.6810	0.3552 ± 0.542	0.3168 ± 0.3567
	BT-TT	6.833±2.787	0.900±0.436	0. .6216± 0.1094	1.9201± 0. .4538	1.1092± 0.3218	0.7015± 0.1592
	MLD	6.200±1.483	0.766±0.235	0.5759± 0.2261	1.7726± 0.7005	1.059± 0.4921	0.5341± 0.2866
WM	BT-TT	4.750±5.560	0.646±0.806	0.5464± 0.1719	1.4980± 0.7286	1.1796± 0.3502	0.5625± 0.2736

Table.7.10 Community structure indices for ostracod species in the different depth layers of the coastal regions of the Bay of Bengal during different seasons (Stations averaged). **S**- Number of Species, **R**- Margalef's richness Index, **I**- Simpson's Concentration Index, **H**$_{(S)}$ Shannon weaver's species diversity index, **€** - Heip's evenness Index, **D**- Pielou's index of species dominance.

Seasons	Depth	S	R	I	H(s)	€	D
SIM	**MLD**	4.400±2.881	1.570±0.675	0.4672±0.1167	1.2521± 0.3965	1.1896±0 .5197	0.5735±0.1033
	BT-TT	9.833±4.401	0.337±1.916	0.7602± 0.1317	2.5948± 0.7330	1.6464±0.4454	0.7541± 0.2021
	300-BT	7.800±4.207	0.871±0.806	0.7282± 0 .1389	2.3981±0.6125	1.5813±0.3405	.7842±0.2003
	500-300	**5.600±2.608**	1.490±0.774	0.6753± 0.1793	2.1003±0.6625	1.6634± 0 .4448	0.7923± 0 .2470
	1000-500	**6.800±3.899**	2.061±0.829	0.5789 ±0.24010	1.9745±0 .6667	1.3269± 0.3735	0.5891±0.2291
SM	**MLD**	**3.167±0.983**	0.314±0.092	0.3766± 0.0962	0.9466 ± 0.1912	0.8447± 0.3899	0.6845± 0.1133
	BT-TT	10.200±7.981	1.361±1.211	0.4334± 0.2943	1.5774± 1.1534	1.5717± 0.4274	0.3874± 0.2495
	300-BT	6.500±3.873	1.036±0.612	0.7294± 0.1106	2.2072± 0.5775	1.7337± 0.2279	0.6787± 0.1341
	500-300	7.750±2.630	1.334±0.308	0.7158± 0.1086	2.2344± 0.5230	1.4967± 0.6048	.7829± 0.1833
	1000-500	7.000±6.055	1.484±1.080	0.7087± 0.1201	2.1985± 0.8097	1.7848± 0.2662	0.6224 ± 0.2292
WM	**MLD**	7.000±3.847	0.967±0.544	0.6725± 0.1332	2.0334± 0.6221	1.5641± 0.5182	0.6861± 0.186
	BT-TT	7.200±4.622	1.325±0.891	0.6773± 0.1813	2.1225± 0.8811	1.640± 0.3190	.6728± 0.2741
	300-BT	**4.800±4.167**	1.325±0.891	0.6312± 0.2117	1.9369± 0.8947	1.7033± 0.2401	0.6037± 0.2789
	500-300	**4.600±4.317**	1.029±1.081	0.5519± 0.1794	1.6061± 0.9117	1.6122± 0.4088	0.4806± 0.2728
	1000-500	**7.600±1.855**	1.029±1.081	0.7513± 0.1413	2.4843± 0.5924	1.8151± 0.5433	.8163± 0.1947

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SUMMARY AND CONCLUSION

Seasonal pattern of distribution of the mesozooplankton community and the diversity of planktonic ostracods in the upper 1000 m of the water column, in relation to environmental parameters in the Arabian Sea (AS) and Bay of Bengal (BoB) are presented. Most of the available literature on the mesozooplankton community of the Indian waters refer either one or two seasons from the upper 200 m water column or a single coastal and oceanic transect, and the data gathered from such studies were not sufficient to delineate all the processes to which the AS and BoB are subjected to. The present study is the first of its kind, which addresses the mesozooplankton community structure in the upper 1000 m of the AS and BoB with in the EEZ and its response to varying biogeochemical processes during different seasons. The planktonic ostracod studies during the IIOE were confined only from the upper 200 m (George, 1968) of the AS and from some selected stations from the BoB. In the present study, the diversity of deeper water halocyprids (up to 1000 m depth) in the AS and BoB has been undertaken in detail with respect to seasons and the prevailing environmental variations.

Sampling was done from 47 stations in the AS and 35 stations in the BoB, during four seasons representing Spring inter Monsoon (SIM), Summer Monsoon (SM), Fall Inter Monsoon (FIM) and Winter Monsoon (WM). Stratified samples of mesozooplankton were collected at all stations from the upper 1000 m depth using a Multiple Plankton Net (MPN) and the strata sampled were 1000-500, 500-300, 300-BT (Bottom of Themocline Depth), BT – TT (Top of Thermocline depth), TT-surface (i.e. Mixed Layer Depth or MLD).

Besides, diurnal vertical migration of mesozooplankton was also studied by taking day and night collections from selected stations. Other biological parameters like Chlorophyll *a* and primary production were also studied along with environmental parameters such as temperature, salinity, dissolved oxygen, nitrate, silicate and phosphate.

The zooplankton biomass in the Arabian Sea generally remained high throughout the year. However, significant seasonal variations were observed in the mesozooplankton biomass in the AS. Monsoonal reversals influenced distribution of mesozooplankton and the differences were prominent in the mixed layer of both coastal as well as oceanic regions. There was marked differences in the physical features of the water column during different seasons. The summer monsoon and the fall Intermonsoon were found to be more productive than spring Intermonsoon and winter monsoon. Further, in the oligotrophic intermonsoon period and the eutrophic monsoon period, there were differences in the zooplankton biomass in the northern and southern AS, suggesting that not only the differences in zooplankton biomass were seasonal but were also latitudinal.

In the present study, the highest biomass values in the AS (average, 1.47 $ml.m^{-3}$) were recorded during summer monsoon especially, in the southern latitudes. Nutrient enrichment by upwelling in the southern coast supported the primary production which, in turn, sustained the herbivorous zooplankton which were succeeded by the carnivorous zooplankton. As a result, the organic production was completely utilized by the higher trophic level organisms in the southern latitudes, leading to a reduction in export flux, compared to northern latitudes. The second peak in the mesozooplankton biomass (average, $0.44ml.m^{-3}$) was seen during fall intermonsoon Warm (SST ~ 28°C), shallow mixed layer (~ 20–30 m) and strong stratification were observed during this period. The high abundance of microzooplankton occurring during this period is probably supporting high mesozooplankton production during this season. During the spring season the mesozooplankton biomass was comparatively high (average, 0.40) in the AS compared to winter monsoon (average, 0.18). The dominant component in the mesozooplankton population was copepods (>80%) during SIM. The copepod nauplii are capable of surviving in tropical oligotrophic waters by feeding alternately on bacteria and picoplankton Thus microzooplankton plays a vital role in transferring the primary organic carbon (from the smaller phytoplankton), to mesozooplankton during SIM. *Trichodesmium erythrium* blooms were the common feature during SIM and have some relation to the dominance of copepods. Some of the copepods, especially the harpacticoid copepods such as *Macrosetella gracilis* use *Trichodesmium* as a food source and as physical substrate for juvenile development. The mesozooplankton biomass was very low in the northern AS during winter monsoon and was represented mostly by carnivorous group. The reduction in the herbivorous zooplankton may be due to the presence of larger diatoms. The grazing of microzooplankton and herbivorous mesozooplankton were poor in the northern AS, due to the dominance of carnivorous zooplankton, as a result the unutilized organic carbon from the euphotic zone was sinking to intermediate depths. Although during the oligotrophic condition, mesozooplankton depends on the microbial loop for food, significant differences were observed in the zooplankton biomass between seasons and latitudes. Therefore, this study is in incongruity with the validity of the Arabian Sea paradox proposed by Madhupratap *et al.* (1996), according which the zooplankton biomass remains more or less uniform due to the microbial loop, despite seasonally varying primary production regimes.

During the present investigation, two distinct marine ecosystems could be identified in the Eastern Arabian Sea namely, the North East Arabian Sea Ecosystem (NEASE) and the South East Arabian Sea Ecosystem (SEASE), that lie broadly north and south of the Findlater jet. NEASE extends between 15° to 22°N and SEASE between 8° to 15°N latitudes. During SM, the SEASE is under the influence of upwelling. The nutrient rich upwelled waters boost the primary production and this is followed by a proportionate increase in zooplankton biomass (average, 5 $ml.m^{-3}$), thus striking a balance between primary production and grazing. Hence, limited export flux and sinking of organic carbon to deeper waters occur in SEASE compared to NEASE. At the primary consumer level herbivory is dominant due to the abundance of grazing zooplanktons. On the other hand, influence of summer monsoon on NEASE is rather limited to the zone of divergence, north of Findlater jet. Productive season in NEASE corresponds with the winter monsoon. Under the influence of the cold and dry north easterlies, surface water along the coast and Open Ocean becomes denser and sinks, causing convictive mixing of waters. These maintain the supply of nutrients to the surface and promote primary production, but the mesozooplankton production was rather low (0.2 to 0.4 $ml.\ m^{-3}$). Carnivory was dominant, in view of the abundance of zooplankters such as chaetognaths, hydrozoans, ostracods and carnivorous fishes. The structure of the biotic community of these two ecosystems, therefore is remarkably diverse, justifying the need to treat them as two distinct ecosystems. On the whole, the pelagic realm of the SEASE is more productive than NEASE.

In contrast to the Arabian Sea, the circulation in the Bay of Bengal is weak and less predictable due to its response to monsoon reversal. The highest mesozooplankton biomass was obtained during summer monsoon than spring inter monsoon and winter monsoon. During SIM, the zooplankton biomass was considerably less in the entire BoB. In highly stratified waters, the primary production and chlorophyll were very low, which adversely affected the growth of mesozooplankton. The reduction in zooplankton may also be due to the warmer and more stratified waters. The general reduction of mesozooplankton may be due to increasing temperature (30.6°C) during this season. Chaetognaths and salps formed a distinct group during SIM. Salps are filter feeders that collect food particles using mucous nets. These mucous nets can become clogged when filtering very high concentrations of particles, which may exclude salps from areas of unusually high particle concentration such as (Harbison et al., 1986) high chl *a* concentrations and primary production (Holm-Hansen *et al.,* 2004). Tunicate growth rates are known to be temperature dependent, and so salps living in warmer waters may grow faster than salps inhabiting the cooler waters.

In the Bay of Bengal also, the highest biomass of mesozooplankton was obtained during summer monsoon. Biomass values recorded at the southern coastal stations were higher than that at the northern coastal stations. Distribution trends of zooplankton biomass closely matched the phytoplankton biomass and primary production. Besides, three concomitant processes (anti-cyclonic warm gyre in the south, coastal upwelling and a cyclonic eddy in the north) were found to influence differentially the biological production in the Bay of Bengal during summer monsoon. In the warm gyre (>28.8 °C), the low salinity (33.5) surface waters contained low concentrations of nutrients. These warm surface waters extended below the euphotic zone, which resulted in an oligotrophic environment with low surface chlorophyll *a*, low surface primary production and low zooplankton biomass (0.14 ml m^{-3}). In the cyclonic eddy, on the other hand, the elevated isopycnals raised the nutricline up to the surface. Despite the system being highly eutrophic, response in the biological productivity was low compared to the upwelling area. In the upwelling zone, although the nutrient concentrations were lower compared to the cyclonic eddy, the surface phytoplankton biomass and chlorophyll *a* were high and the mesozooplankton biomass (1.12 ml m^{-3}) was also high. Normally in oligotrophic open ocean ecosystems, primary production is based on 'regenerated' nutrients. But during episodic events like eddies the production switches over from 'regenerated production' to 'new production' This switching over in the open ocean (during cyclonic eddy) and the establishment of a new phytoplankton community would take longer time than in the coastal system (during upwelling). Although the cyclonic eddy and upwelling being divergent processes (transporting of nutrients from deeper waters to surface), the better utilization of nutrients leading to enhanced biological production and its transfer to upper trophic levels in the upwelling region imply that the energy transfer from primary to secondary level (mesozooplankton) is more efficient than in the cyclonic eddy. The results suggest that basin-scale and mesoscale processes influence the abundance and spatial heterogeneity of plankton populations across a wide spatial scale in the BoB. The multifaceted effects of these physical processes on primary productivity thus play a prominent role in structuring of zooplankton communities and could consequently affect the recruitment of pelagic fisheries.

The zooplankton standing stock in the BoB during winter was comparatively lower than that of SM and SIM. Strong stratification during the WM prevented vertical mixing resulting in oligotrophy, and low primary and secondary productivity. The seasonal difference of mesozooplankton biomass was significant in the mixed layer of the coastal stations than in the open ocean stations. All these seasonal variations observed in the BoB can be attributed to the variability in the hydrographical parameters and the associated primary productivity patterns.Compared to the Bay of Bengal, the Arabian Sea recorded high standing stock of mesozooplankton which was ~3 fold during the SM. Even in the oligotrophic seasons, AS possess comparatively high standing stock of mesozooplankton.

During the present study, diurnal studies were undertaken from selected stations in the AS and BoB, to find out day and night variations in zooplankton biomass. An active diel vertical migration (DVM) was observed during SM and FIM in the AS and only in SM in the BoB. DVM of mesozooplankton showed that it was more prominent during the highly productive SM in both basins. DVM showed strong associations with factors like chlorophyll *a* and stratification. Periods of extended migration coincided with elevated concentrations of chlorophyll *a* in the surface layers. But when there was stratification, DVM was weak and the most extended periods of DVM were observed when there was no stratification. Some larger and coloured crustacean groups showed active migration during night. Reverse migration was also observed in copepods and fish eggs and larvae. Statistically significant seasonal difference was observed in the zooplankton biomass of night and day between the oceanic and coastal regions, respectively of both AS and BoB. It can be concluded from the study that DVM is an important feature of the zooplankton community in the southern AS and BoB during SM and those vertical migrants may help in removing significant portion of carbon from the surface layers.

The community structure of planktonic ostracods in the AS and BoB was also investigated during the course of the study. In all 55 species were identified, of which 51 species were from the AS and 55 species from the BoB. Among this, 14 and 18 species were newly recorded from the AS and BoB, respectively. The highest abundance of ostracods was observed during SM in both AS and BoB.

The most abundant species in the AS was *Cypridina dentata* and followed by *Euconchoecia aculeata* and their abundances varied between seasons and depth strata. There was significant variation between the ostracod community in the coastal and oceanic stations of the AS. In the coastal stations maximum abundance of ostracods in the MLD was recorded during the SM while in the oceanic stations, it was during WM. The bioluminescent species encountered in the AS and BoB were *Alacia alata, Cypridina dentata, Conchoecia subarcuata, Conchoecia magna, Conchoecila daphnoides, Conchoecissa imbricata, Orthoconchoecia bispinosa, Mikroconchoecia curta, Discoconchoecia elegans* and *Paraconchoecia spinifera.*

Ostracods contributed significantly to the biomass of zooplankton in the AS with unusually high density due to swarming. The maximum density of the *C. dentata* swarm (64900 ind.m^{-3}) was observed during the WM at the oceanic stations of northern latitudes (19°-22°N). From WM through FIM (SIM, SM), the intensity of the swarms varied from region to region (off 17°-19°N, 15°&17°N and off 10° &15°N in that order).

In this study, an attempt has been made to understand the factors influencing the swarming of *C. dentata*. The hydrographic condition of the swarming area was marked by high saline watermasses (>36.2), having relatively low temperature (<26°C). This environment appears to be the most favorable one facilitating rapid propagation of this species. Chlorophyll *a* concentration, although did not directly influence the propagation of this species, it had an influence on the increased density of the swarming population. From this study it could be deduced that swarms of *C.dentata* occur only in high saline waters (>36.0) having low temperature (<26°C) and it is proposed that the swarms of *C. dentate* are invariably an indication of the presence of the Arabian high saline water mass (ASHSW).

The most abundant species in the BoB was *Euconchoecia aculeata* and its overwhelming dominance was due to changing hydrographical regime. In the BoB, *C. dentata* was present only during SM and restricted its manifestation and distribution up to 15°N. During the SM, the high saline ASHSW from the AS intrudes in to the BoB and the intrusion has been observed off the southern Bay (up to 14°N) at a depth of 50 to 100 m. So the occurrence of *C. dentata* during this season in the BoB confirms its affinity to the high saline ASHSW. The BOB exhibited high species richness and diversity compared to the AS. Higher number of newly recorded species (18) in this study as compared to that of IIOE suggests the possibility of the existence of the even higher diversity in deeper waters of the Northern Arabian Sea.

It has been suggest that alternative carbon sources (protozoans and microzooplankton) play an important role in the diet of mesozooplankton during intermonsoon seasons. Future research should aim to assess the seasonal role of alternative sources of carbon in the diets of mesozooplankton, particularly in the oceanic regions of AS and BoB. Predation of mesozooplankton by omnivorous macrozooplankton appears to exhibit seasonal variation. It can be assumed that mesozooplankton, the major consumers of phytoplankton, transfer carbon to deeper depth and enhance the local efficiency of biological pump. The study revealed that diel vertical migration of zooplankton was significant in the AS and BoB. It is therefore important to have seasonal studies to examine the vertical flux of carbon in the AS and BoB to assess the role of this region to the carbon cycle. In addition about 11 species of bioluminescent ostracods were identified and most of them were highly abundant in AS, which can be useful for further studies on biophotonic research and for naval purposes.

Prior to the present study there was gap in the information on zooplankton production, distribution and the community structure of ostracods in the AS and BoB. The present study provides a key information for future studies on zooplankton and fishery oceanographic studies in the AS and BoB.

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